Ralph W. Pope.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, Jan. 3, 1902.

The 159th meeting of the INSTITUTE was called to order at 8.25 P. M., President Charles P. Steinmetz in the Chair.

SECRETARY POPE:—At the meeting of the Board of Directors this afternoon, the following associates were elected:

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Total, 34.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

METHODS OF ILLUMINATION.

BY LOUIS BELL.

At the risk of being iconoclastic, I am here going to discuss the art of illumination from its human and practical side rather than the technical details of electric lighting, and to compare methods as bearing upon the result rather than in their theoretical relations.

Artificial lighting in some form or other has come down to us from the very dawn of history, but without material change in methods and apparatus, until well into the last century. Its resources have been vastly increased within the past seventy-five years and have grown up with the rise of what one may call technical civilization. The development of electric lighting which has taken place during the last quarter century has enriched the art with extraordinary facilities, and it is the bearing of these upon the art in general and upon each other that forms the subject under discussion.

Now, at the very outset, I must confess the profound conviction that as things are at present we are using the tremendously potent means at our command with a reckless indiscrimination that in the long run profits little to art or civilization. We have contracted in no small degree the modern and peculiarly American vice of megalolatry, if one may venture to coin the word, and estimate illumination like many other things by the magnitude of the display.

It is difficult to realize in this the change that a century or so has wrought. As nearly as we may estimate from the somewhat meagre data that have come down to us, the most splendid fete in the days of Louis Quatorze glittered with less than a fifth the illumination that makes conspicuous the *bourgeois* tawdriness of a twentieth century function,but who shall care to say that ratio represents a gain to art or a new conception of regal magnificence? Art and civilization do not necessarily gain with added physical resources. Better the rush light that shone on the wine stained doublet of Will Shakespeare than the electric arc with Mallock and Oscar Wilde.

The truth of the matter is that with the immensely powerful sources of light now at our command, there is a constant and often reprehensible tendency to turn on more and more light irrespective of quality and of actual needs until the net result is loss rather than gain. We too often forget that illumination is a problem at once physiological and physical, and that by reckless profusion of light it is a perfectly easy matter to key the vision as it were, up to a pitch which demands extraordinary methods to produce the most commonplace results.

It is a fundamental physiological fact that the eye works equally well, sees with equal facility, within a very wide range of illumination. True, as the light intensity is reduced a point is finally reached at which the normal eye begins to labor and strain, picking out details instead of grasping the whole, but it is equally true that if the lighting is carried above a certain intensity the eye reaches a point where it not only gains nothing in ease of perception, but suffers from over-stimulation. Between these limits, varying obviously for different tasks, there is no intrinsic reason for increasing or diminishing the illumination except in so far as a reason may be sought in convenience or economy.

Whatever the methods employed, the end of artificial lighting should be to furnish illumination in quantity fully adequate for the conditions to be met, and in quality such as will neither unduly strain the eye nor in any way inconvenience the user. It is the adaptation of means to end that should be sought here as everywhere else. From this standpoint, quality is more important than quantity. It is no easy matter to define the quality of light in any simple terms. Certain qualities, however, must be possessed by any really good light in order that it may not do positive injury to the eye and may prove efficient visually. The three most important qualities for a practical illuminant are in the order of their importance as follows:

1. Steadiness.

2. Suitable intrinsic brilliancy.
3. Suitable color.

1. *Steadiness.*—The importance of this property cannot be over-estimated, for without it in a rather high degree an illuminant is both impracticable and dangerous to the eye. An unsteady light works evil in two distinct ways, somewhat different in their relation to the physical properties of the light. In the first place we must remember that the eye is provided with a partial defense against unsteadiness in the visual inertia given by the persistence of retinal impressions, and that in addition it has the iris working automatically to steady the amount of light which reaches the retina.

A flickering, unsteady light may injure the retina through overworking it by a rapid succession of violent stimulations, or it may tire the automatic mechanism of the iris, or it may do both. The iris is peculiarly a defence against slow changes in illumination. At full aperture it has 15 or 20 times its area at minimum aperture, or perhaps double this ratio under extreme conditions, but its time constant is large, several seconds, and in an unsteady light it never gets a chance to settle into a position of equilibrium. Visual inertia is a defence against very rapid changes, but not against slower ones and there is a wide range of frequency between the point at which visual inertia fails to protect and the point where the iris can give material aid. Within this range, unsteadiness, whether accidental or periodic, may be both distressing and dangerous.

Let us try if possible to get a quantitative conception of this case. The frequency at which flickering in incandescent lamps becomes annoying is a much mooted point, the view of the debater generally depending on what he has to sell. The real question, however, is what variation in amplitude of illumination constitutes an amount which is physiologically serious if periodically repeated. Obviously a change from light to darkness is vastly worse than a small change in brilliancy at the same frequency. Eyes differ in sensitiveness, but in my own case I have found that a variation of 10 per cent. at the rate of one or two maxima per second is very annoying and tiring. This observation was made, by the way, with the potent assistance of a pumping synchronous motor which could give variations in voltage up to five volts on an ordinary incandescent circuit. Retinal persistance is of course a very variable phenomenon, but for a rough approximation taking this constant at 1/5 second, a 10 per cent.

falling off in brilliancy would correspond to about 1/50 second, and one would feel entirely safe in saying that sudden flashes 1/50 second apart would cause trouble at once, and, probably owing to frequent recurrence, very serious trouble. In point of fact, an alternating arc worked with small current density gives such a succession of flashes, and in spite of a certain amount of thermal stabiliiy would be quite impossible at 25∼, and is bad even at 50∼ per second. Incandescent lamps, having greater thermal stability, present smaller fluctuations due to frequency, but are very bad at 15∼ to 20∼, and show fluctuations troublesome to some eyes up to and even above 35∼.

Under conditions of prolonged use, fluctuations considerably less than 10 per cent. may become troublesome as is well shown by the evil effects of flickering gas burners, in which the changes of absolute intensity are small. Here, of course, the phenomenon is complicated by flickering at the edges of the retinal image, but taking all the facts together, I think that one may safely say that any source of light subject to rapid and frequent variations as great as 5 per cent. is unfit for use as an illuminant for work requiring steady use of the eyes. Much greater changes occurring slowly enough for the iris to act with them, or at infrequent intervals can be tolerated without inconvenience.

2. *Intrinsic Brilliancy.*—The brightness of the radiant used in artificial lighting is a matter of great physiological moment. If the image of a brilliant light remains on one point of the retina, it may and probably will produce serious over-estimation, and the bruised spot, as it were, may become the nidus of painful and dangerous inflammation. Any oculist can report a long list of serious or destructive injuries due to this cause. On the other hand, if the image wanders over the retina rapidly, it produces in a minor degree the same unpleasant result experienced in coming suddenly from a darkened room into bright sunshine. Especially is this true if the brilliant radiant now and again dodges into the field of vision without giving the iris a chance to act. The fundamental rule of proper illumination is to keep brilliant radiants out of the field of vision. Apart from the mischief done. the iris in the presence of such a radiant shuts up as far as possible, and objects not brilliantly illuminated are seen with great difficulty. Hence, the common experience of being unable to see across an arc light, and the serious difficulty thrown in the way of pilots by search lights unwisely displayed. It is a common experience, too, that shading a brilliant radiant may greatly

improve the seeing conditions in a given space while actually reducing the available illumination. It is almost impossible to get a quantitative measure of such a gain, though it is often quite marked. The ingenious illuminometer of Messrs. Houston and Kennelly, and the tint comparing instrument of Mr. Bijur, another fellow member, both break down here since, they work a shielded eye.

The real criterion of visual usefulness is not the illumination I, but the product $I\ \sigma$, where σ is the effective aperture of the iris; and since this latter factor is a function of the brightest radiant in the field we may properly write the criterion

$$\frac{I}{f(B)}$$

where B is the intrinsic brilliancy of the radiant. This whole subject needs investigation, but like other matters involving subjective facts, it is very hard to get at. We can, however, get an approximate notion of permissible values of B for practical purposes. The experiments of L. Weber on intrinsic brilliancy give a clue to the conditions found in practice. Reducing them to mean values and candle power per square inch, some of his results are as follows, approximately:

Horizontal white card, in brilliant sunlight.......	25
White sunlit cloud	7
Argand burner................................	6.5
Horizontal white card, dull winter day...........	0.26

Now there is no doubt whatever that the intensity first mentioned is far too great for comfort, considering the normal eye. It is, in fact, extremely trying. The second and third, most of us would consider rather uncomfortably bright if they were fairly in the field of vision, and all the experience along this line seems to indicate that for radiants within the field of vision at the distances ordinarily met with in interior lighting an intrinsic brilliancy of 5 C. P. per square inch is quite as high as it is wise, for hygienic reasons, to go, and better rather less than rather more. This indicates at once for the radiants in common use, that they should never be employed within the working field of vision without diffusing shields to keep down the intrinsic brilliancy.

Obviously, with the given limit of intrinsic brilliancy, the diffusing globes must be of fair dimensions. With proper diffusion the entire globe surface may be taken as the radiant, and for a first approximation the radius of a spherical diffusing globe should be at least

$$r = \frac{\text{C P}}{\sqrt{5\pi}}$$

C. P. being the candle power and r being in inches. With very high intrinsic brilliancies, such as are given by arc lamps, it is hard to avoid the appearance of a nucleus of great brilliancy, and proper diffusion means considerable loss of light. But arcs should be kept for the most part out of the working field of vision, so that this objection is not so serious as might otherwise be the case.

3. *Color.*—It is not necessary that artificial illuminants should conform to a particular color standard, save where color is a matter of prime importance. It is, however, true that the general applicability of a light is very strongly influenced by its hue, and that broadly, strongly colored lights would fail conspicuously in visual usefulness. Quite aside from the matter of color perception, it is the orange, yellow and green that make up the working luminosity of the spectrum formed by sunlight to the extent of about 80 per cent., and even were a brilliant deep blue or red light produced it would require far greater energy for the same luminous effect than a yellow or greenish light.

The eye unquestionably does its best work by light approximately like that through which it has been evolved. But sunlight is a very variable quantity. Outside the atmosphere the sun would appear conspicuously blue, but we live and move and have our being inside the atmosphere, and the color of the illumination outside is only of academic interest. On the meridian the sun gives light that is to all intents and purposes white, but as it declines, the atmosphere steadily filters out the blue and violet, until by the middle of the afternoon the entire blue end of the spectrum is down to about half its previous intensity, while the general luminosity has fallen only about 20 per cent. The general color tone is then distinctly yellowish white, and still later in the day when the sun is only a few degrees from the horizon, the blue contingent is practically wiped out and the light shades off from orange yellow to orange red. Brilliant diffused light, being mixed with considerable sky light, which is noticeably blue, for the very reason that the setting sun is not, is perceptibly richer in blue rays than average sunlight.

For our purpose, the conspicuous fact about natural light is that it seldom or never verges on the blue or violet, and never is tinged with blue green, green or yellowish-green. Its average tint is slightly yellowish-white, with a tinge of orange late in the day.

A color match made at high noon will not hold when the sun is on the horizon, but memory of exact color value is not much to be trusted, and the knowledge that the tints did match at noon usually convinces the observer at sunset that "the light is poor," any variation being attributed to lack of light rather than to its real cause, change of hue.

As regards artificial lights, generally supposed to fail conspicuously in giving what we are pleased to call "natural" color effects, every one of them, except the enclosed arc, which is strongly bluish, and the Welsbach, which is greenish, can be matched by normal sunlight at some time of the day. Even a Hefner lamp is not redder than a low sun on a hazy day.

The ideal artificial light from a purely utilitarian standpoint should represent average sunlight. So far as artistic results are concerned, from the present canons of human taste, a light weaker in the blue and green is to be preferred. Taste may some day be evolved to a point where a thallium-green illumination will be considered becoming, but we are not there yet.

So far, then, as color is concerned, one can plan for artificial illumination with reasonable freedom of choice. It is by no means clear even that it is always desirable to employ white light for color-matching, unless one can guarantee that the match will be viewed only by white light. An enclosed arc worked with rather small current and untinted globes will distort average or normal color values quite as much as will gas light. Hence, the importance of enclosing shades which correct color as well as diffuse light.

Classes of Illumination.—One may broadly divide illumination into (1) *General* and (2) *Directed.* Each class has its own relations to the requirements for quantity and quality, and each may be further subdivided. But so far as methods and the choice of illuminants are concerned, there is an important distinction between light intended to be generally diffused and light intended to facilitate particular operations at particular points. It is in the adaptation of methods to ends that the *finesse* of the art appears.

If by some new invention the energy required to produce one candle power in illuminants of all classes could be cut down to one-half its present value, the world would be in an uproar over it. But it is well within the truth to say that skilfully treated, illumination will effect at least an equivalent saving, or will give vastly better results for the same expenditure of energy. Highly efficient radiants are *per se* very desirable, but if efficiency is gained at the loss of other important qualities, it may be dearly bought. Illumination, visual usefulness, is the thing to be sought. On this basis it has been often maintained with some show of reason that the working unit by which practical lighting should be measured and practical radiants judged is illumination rather than intensity.

Illumination vs. Intensity.—In favor of using the measured illumination as the criterion by which to judge sources of light, it may properly be said that illumination rather than light intensity is the thing which is practically important. Illumination is the object of artificial lighting, and it is a matter, from this standpoint, of no particular consequence whether the radiants have one or another particular intensity so long as the result is achieved.

On the other hand, I have already shown that the real criterion in artificial lighting is not the illumination as measured in certain conventional ways, but what I have called " visual usefulness " ; *i. e.*, the illumination as modified by the way in which the radiants are applied. Moreover, illumination is an extremely difficult thing to measure with precision. There are difficulties enough in ordinary photometric measurements, even when pursued with the aid of the best modern apparatus. The difficulties in the way of measuring illumination in terms of the lux or candle foot at various points in a space that is artificially lighted are ten-fold greater. It is photometry with all the conditions against precision, and even with the illuminometer of our confreres Houston and Kennelly, as good an instrument as yet devised for the purpose, the mean error of a single observation is stated by the inventors to be about ten per cent. It and all of the instruments of its class for the purpose of measuring illumination have proved, as a matter of experience, to be both rather slow and rather inaccurate; hence, such measurements are in themselves unsatisfactory as means of passing final judgment upon commercial lighting.

It should further be said that the instruments for measuring illumination as such, seem to be afflicted with peculiarly large personal errors. Some observers, otherwise careful and trustworthy, are unable to get coherent results from them at all, while occasionally one acquires a knack in their use so as to obtain very consistent results, which, however, are more than likely to vary widely from the results obtained by another successful observer.

Aside from this, even were it possible to make measurements of illumination with precision, illumination is not in the last resort the thing which we are really after, which is the power to see, *i. e.*, visual usefulness, and this involves physiological quantities of which it is almost impossible to take physical account.

Moreover, the testing of lighting by illumination, pure and simple, involves the art of placing radiants, and while commercial measurements by illumination might tend to develop this art, they will also afford almost unique facilities for meeting the letter but not the spirit of the specifications, facilities which are only too great in the case even of intensity measurements upon commercial illuminants, which are susceptible of determination to a fair degree of accuracy. Hence, in view of all these facts, I believe that attractive as measurement of illumination, or still better, visual usefulness may be in theory, in practice it will prove far better to fall back upon intensity measurement on which the illumination measurement must finally depend.

As a rule, I have observed that there is a tendency to favor measurements of illumination chiefly on the part of those engaged in exploiting illuminants that cannot satisfactorily stand comparison on the basis of intensity.

We must then, I think, judge commercial illuminants so far as their quantitative relations are concerned, by intensity measurements, leaving their qualitative relations—some criteria regarding which have already been suggested—for consideration on their merits.

The Intensity of Illuminants.—The fundamental measurement, then, on which one must base all comparison of methods of of artificial illumination is the measurement of the intensity of the radiant.

I have neither time nor disposition here to bore the INSTITUTE with any discussion of the technique of photometry. The general methods and apparatus, however, are worth some considerable notice.

To my mind the chief desideratum in dealing with matters of artificial lighting is the settling down of practice on some conventional basis, as regards a standard of light. Working standards may be easily constituted from incandescent lamps, but to obtain a primary standard reproducible with a good degree of precision, and answering reasonable requirements as to color and steadiness is a very different matter. The literature on the subject is large and our INSTITUTE committee has added not a little of value to researches bearing on the subject, but up to date there certainly is not in general use a standard which anywhere nearly meets requirements. The Violle platinum standard, which was a laudable attempt to obtain a standard light which in a general way would fall in line with the C. G. S. system may be said to be practically non-existent. It has not proved to be properly reproducible and the experience of most of those who have tried it is, that it is a ticklish and uncomfortable sort of standard to deal with; consequently, its sub-multiple, the *bougie-decimale*, must be regarded as a species of luminous phantasm so far as present practical developments are concerned, and with the *bougie decimale* should tentatively be classified its derivative, the *lux*. Lux is the conventional name for the fundamental unit of illumination, but so long as it is referred back to the *bougie decimale*, which is not a practical standard of intensity, it must remain in a species of scientific limbo from which in due time I trust that it may be freed.

As practical standards we have in use in the scientific and commercial world, the English standard candle, which is the only one having in this country a legal recognized existence; the Hefner-Altneck lamp adopted by the International Congress of 1896, most thoroughly investigated by the Reichsanstalt and scientifically in good repute; the German candle, perhaps now tending to pass out of use; the French Carcel lamp and the Vernon-Harcourt pentane lamp now developed in a 10 C.P. size.

The relations between these various standards of intensity are only approximately known, each fresh investigation of the subject tending to give a new set of values differing very materially from the last.

The English candle we have all used and, I think, have cordially disliked. It is not very accurately reproducible, although conveniently so. It is not steady to a suitable degree. It is rather small for work with commercial radiants and only fairly good in color. It is, however, the legal standard in this country and so long as it remains so must be treated with a certain degree of respect.

The Hefner-Altneck lamp, on the other hand, is quite accurately reproducible and fairly steady. It is, however, open to two objections so grave that they must inevitably ere long cause its rejection as a general standard. These objections are its very small intensity and its extremely bad color; indeed, its use as a standard involves the problems of color photometry in a somewhat aggravated form. Any one who has often attempted to balance the Hefner-Altneck lamp against an incandescent for example, will realize that although consistent results can by extreme care be obtained, the comparison is a distinctly troublesome one and not what one would care to permanently depend upon as the basis of scientific measurement. It is essentially a difficult comparison.

The Carcel lamp is somewhat better in the point of reproducibility and steadiness than the English candle, and not as good as the Hefner-Altneck lamp. Its intensity is decidedly more convenient, however, and its color is better than that of the Hefner-Altneck lamp. It can hardly be considered, however, as a standard which is likely to be used in an international way and certainly is without standing in this country.

The Vernon-Harcourt pentane standard—the present legal standard in London—deserves, I think, respectful consideration. It has recently been carefully looked into by the committee of the American Gas Lighting Association with somewhat encouraging results. This committee found a very satisfactory degree of constancy under rather widely varying conditions. The point of greatest interest in its report was that pentane of practically constant quality is commercially obtainable, so that so far as the material consumed goes, this standard would seem to be satisfactory as the amyl-acetate one as regards reproducibility. The constancy appears to be satisfactory, and the color and magnitude of the standard are such as to give it a strong claim for consideration. It has not yet been investigated so completely that a final estimate of its desirability may be formed, but I am much inclined to the opinion that a standard of as high intensity as this is very desirable and that this particular standard is worthy of very serious investigation.

I have passed by in this brief enumeration the Methven screen which is in considerable and successful use as a secondary standard, but concerning which the concensus of opinion seems to bear out the view that in point of reproducibility and constancy it leaves something to be desired.

Such, then, is the state of things as regards standards and the unsatisfactory nature of the situation is not open to debate. The most important step to be taken in the reduction of illumination to a practical condition, is the general acceptance of a primary standard even as a tentative matter, so that instead of various investigators working with standards bearing only approximately known ratios with each other, they shall, at least, deal with the difficulties and errors involved in the practical use of a single standard. At present we have results given in candles, decimal candles and Hefner units, and we have to look carefully at the investigator's preface to discover to which of these he has temporarily pinned his faith.

As derived units of illumination we have the lux, in theory based on the decimal candle, and occasionally passing into variants, like the candle meter, using the English candle, or the Hefner-unit meter in its turn.

Still apart from these we have the candle-foot, which falls in logically enough with our English measurements, but can never be satisfactory as an international standard. Considering the uncertainties at present existing in the fundamental units in the matter of intensity, it is small wonder that the derived units are likewise in a bad way. The logical derived unit, which has the greatest importance in a practical way, is the unit of luminous flux, called lumen in the tentative nomenclature of the Congress of 1896. The conception of light out-flowing from a center and all available light as a quantity based upon this conception, is a most useful one. The total light given by any radiant must evidently be expressed in some such way as this, in order properly to take account of its sometimes very great variations in different directions.

As regards the much-mooted question of a conventional direction of measurement, in comparing radiants, it seems to me that the application of a little common sense simplifies the problem wonderfully. If light emitted in all directions from a radiant point may be useful for the purpose of seeing—a proposition which scarcely admits debate—then the total luminous flux is the thing which ought to be measured. If for a particular purpose, under particular circumstances, concentrated light in one direction is desirable, then for that purpose and under those circumstances, light in that direction should properly be measured. It is the case of general illumination on the one hand and directed illumination on the other.

The light from various radiants is distributed in a very diverse fashion. The commonest distribution is that of a more or less flattened ellipsoid, with cusps more or less pronounced at either extremity of the axis. Whatever the peculiarities of the distribution, the total light-giving power of the radiant as a whole is settled once for all by its mean spherical value. There is no other method of measurement which gives even an apporximate value for the total luminous power which that particular radiant furnishes. In the last resort, this total luminous radiation is the important scientific quantity, and hedge it about as we may with certain conditions as to its distribution, in comparing the efficiency of radiants as regards light-giving power, mean spherical intensity is the only ground in common upon which all can stand.

As Chairman of the Committee of the National Electric Light Association for the rating of incandescent lamps,I have wrestled for the past five years with the intricate and annoying problem of finding for commercial convenience,if possible, some equitable and simple method of applying a common test to radiants differing even so little in their distribution as do incandescent lamps, and after canvassing the whole question and examining a vast amount of data on the subject, after struggling to escape from the details of the somewhat intricate mean spherical measurement, I am compelled to fall back upon it as the court of last resort in matters of illumination.

I shall speak later of some of the annoying practical considerations that have entered into this conclusion. The mean spherical standard, however, is the common basis upon which all radiants can fairly meet for a judgment of their total light-giving power and for a comparison of the total luminous energy which they furnish, as related to each other, and as related each to its own consumption of kinetic energy. Many objections based upon so-called practical considerations have been raised to this primal rating, but they have been and are uniformly raised by those exploiting illuminants which can be measured in some other way more advantageously to themselves.

It is perfectly natural from the commercial standpoint for one to desire that his particular radiant should be measured in its direction of maximum candle-power. It reminds me of the early arc lamp salesman who vociferously lauded his particular system before a board of aldermen as furnishing lights of 8,000 candle power, and when asked for an explanation promptly replied that his lamps were placed at the corners of two intersecting streets and gave 2,000 candle power up and down each street. If that was not 8,000 candle power,he would like to be informed why not. There likewise have been, not infrequently, objections raised to using a candle power or similar rating at all, or indeed the falling back upon photometric measurements of any kind, but in all such cases it is entirely safe to assume that a mean spherical measurement of the objector's particular illuminant on a purely photometric basis would disclose very potent reasons for his disinclination for having such a measurement made.

Practical Illuminants.—As electrical engineers in dealing with problems of illumination we practically make use of the following classes of illuminants: open arcs, enclosed arcs and incandescent lamps of various types and efficiencies, to which we must now add the " Nernst " type of lamp.

We may, perhaps, look forward in the future to luminescent lamps of one type or another, but at present these, I regret to say, have no practical bearing upon the art of illumination. These available radiants differ in all the properties which go to make up a useful illuminant, and possess, each of them, vices or virtues more or less important with respect to their adaptability to the solution of various practical problems in artificial lighting. It is perfectly safe to say that no one of them has shown, up to the present, such conspicuous superiority in all particulars, as to give any logical reason for adopting it to the exclusion of the others. They vary widely in total power, in intrinsic brilliancy, in steadiness, in color and in efficiency, and all of these properties have to be borne in mind in adapting them to practical business.

General Illumination.

By general illumination I mean such illumination as is ordinarily required for illuminating considerable spaces in-doors or out.

General illumination is intended—so far as in-door use is concerned—to give light for the ordinary vocations or amusements which people carry on after nightfall, and must be proportioned in intensity and color to the requirements of these conditions.

General illumination out-doors is for similar general purposes, but the requirements for it differ from those for in-door lighting, by reason of the fact that general illumination out of doors is not for the purpose of enabling one to do any particular work, least of all work requiring a strong light, and consequently is usually very much less in amount than general illumination in-doors.

Moreover, inasmuch as the chief use of illumination out of doors is to enable people to get about conveniently, or at the most to handle rough work expeditiously, its quality in color, brilliancy and even in steadiness, need not come up to the mark which is at once necessary if one attempts to read or to carry on ordinary work by the light in question.

In recent times the tendency has been to use arc lamps for all general illumination out-doors, reserving in-door work for incandescents; a task which they have shared in varying proportions with ordinary gas or gas in some of the modified mantle burners. The chief merits of the arc for out-door work are cheapness and power.

The old open arc, which until the last few years has done the bulk of general out-door lighting, possessed the merit of giving at a high efficiency a very powerful light at a moderate price. Its conspicuous demerits were great unsteadiness and intrinsic brilliancy so high that it either had to be shaded or else installed so high above the ground as to be practically out of the field of view except from a distance.

The old open arc was, as all of you know, of two general types: the high voltage arc, *i. e.*, the ordinary type at about 50 volts, and the old low tension arc of about 35 volts pressure between the carbons; the amount of current used in the two being practically inversely to the voltages employed.

The former type was the one which survived the earlier years of electric lighting, and the so-called 2,000 candle-power arc, taking about 9.5 amperes, was generally regarded as standard for out-door work. In point of fact, this open arc was and is the most powerful radiant practically used for exterior illumination. Its great intrinsic brilliancy was always an objection to its use indoors or near the ground, and its distribution of light—said distribution being largely in a narrow zone about 45 degrees depressed from horizontal—was not such as to answer successfully the requirements of street lighting. The consumption of carbons was rapid and the lamps seldom burned steadily. In-doors the case for such arcs was much worse. They were too bright, too irregular in distribution and far too unsteady for such illumination. From a mistaken notion of economy, also, they were generally installed in too few numbers, each arc replacing about twice the number of gas jets which it ought to have replaced, with the result of giving an unequal illumination with very sharp and dense shadows that proved extremely annoying to the eyes, and the visual usefulness of which was extremely limited.

With the growth of constant potential circuits special open arc lamps were devised, which overcame in a measure certain of these difficulties, particularly the unsteadiness. The difficulties of too great brilliancy and bad distribution remained, however, with the open arc even in this improved form.

Abroad it has been and is the practice to use two and sometimes three constant potential open arcs in series across the ordinary lighting mains, and owing to the fact that carbons of a very high quality are available in Europe at a low price, in point of steadiness the Continental type of open arc has generally proved very satisfactory; while the installation of two or three in series so greatly increases the output of light for a given expenditure of energy when working on a constant potential circuit that one can afford to enclose the arcs by dense diffusing globes, which almost entirely obviates the difficulty of too great brilliancy.

In this country, as you all know, the recent tendency has been entirely toward the enclosed arc. The great economy of carbons and of labor, together with the steadiness of the light and the improvement of the distribution by the lengthened arc and by the diffusing inner globe, have operated to bring such arc lamps into constantly increasing use both in-doors and out. It must be said, however, that enclosed arcs have one fault for in-door work which may become and often is very serious, *i. e.*, a tendency toward an exaggerated bluish white or even violet hue, which makes the illumination derived average as bad in point of color as in any known artificial illuminant.

A tale is current in the profession, of a certain grocer in a New England city, which shall be nameless here, who exposed for sale in front of his store a large box of cranberries, only to have them admired as the biggest blueberries of the season when evening came and the enclosed arc hanging in front of his store put in its work upon the cranberries.

This is but a slight experience of a condition which may exist and which seriously hampers the usefulness of certain kinds of enclosed arcs when used in-doors.

For most out-of-door work the bluish tinge of the enclosed arc lamp is not an objection. Its steadiness is admirable and its distribution is so very much improved that for street lighting the uniformity of illumination is far greater than that attainable by the earlier form of open arc.

Still more recently the enclosed alternating arc has come into wide use for street lighting and to a less extent for in-door work. The distribution of light from this radiant is even somewhat better than that from the enclosed direct current arc. The intrinsic efficiency of the alternating arc, however, is distinctly less than that of the direct current arc and compensating advantages have to be sought in its somewhat better light distribution and in the somewhat better efficiency of the apparatus by which the energy is delivered to the lamps.

I may not here enter into the question of alternating current vs. direct current for arcs for street lighting, since it is one which could be threshed away at for the entire evening without saying half that could be said. Suffice it to say that if one uses the alternating arc, it is in my opinion necessary to provide somewhat more energy per lamp than in the case of the direct current arc, either open or enclosed. The efficiency of the lamp for street lighting may be expressed in gross candle power, in illumination within a certain specified radius, and by the minimum illumination at the extreme distance between lamps.

So far as absolute brilliancy goes, there is no question that the old 2,000 candle power open arc gives a greater luminous flux than any of the improved arcs which have replaced it. Its distribution of light, however, is open to serious objections on the score of general economy, for the centre of the zone of the maximum of illumination falls at a distance from the foot of the lamp post equal to the height of the lamp above the pavement, and within and without this zone the light falls off somewhat rapidly. Both the direct current and alternating current enclosed arc throw the maximum of light nearer to the horizontal and hence produce a larger and better illuminated area.

If the open arc could be used with a proper diffusing globe, such, for example, as the Holophane globe, sometimes, but rarely used on arc lamps, it could undoubtedly duplicate the more uniform distribution of the enclosed arcs at increased efficiency; but any efficient plan for redistributing light in this way means working with the arc in a fixed focus; *i. e.*, it means practically a focussing lamp, if the carbons are rapidly consumed, as they are in open arcs. The increased cost of the focussing lamp has so far debarred its use in this country, so that the open arc has been denied the advantage of such fixity of the radiant point as would be desirable.

We judge the illumination of a street by two things; first, by the light actually delivered at the surface of the ground; second by the general illumination produced along the street

A light which merely renders luminous the dull surface of the pavement, leaving the houses and objects along the street in comparative darkness would not in the long run prove to be a satisfactory means for lighting a street; hence, one must take into account the general light delivered as well as that furnished on the plane of the ground. Light delivered much above the plane passing horizontally through the lamp is of comparatively no effect in improving general illumination, unless the lights happen to be in narrow streets bordered by unusually high buildings. A view of any large city from a considerable distance at night gives a vivid idea of the waste of luminous energy which goes on. Sometimes for many miles the lights of a city are visible by the reflection upon the clouds and diffusion from the floating particles in the air above the city.

As to the practical lights used for street lighting, it is hard to suggest a fair and adequate method of rating. Out-door work differs radically from in-door work in one very important particular; *i. e.*, in the aid which is received from diffusing surfaces. Out-of-doors there are practically no diffusing surfaces of any importance on which the light falls, except the ground when snow-covered in winter. In-doors the aid received from the diffusion is very important, as we shall presently see; hence outdoors, rays thrown much above the horizontal are comparatively ineffective. Rays thrown directly downward need not be strong in order to produce adequate illumination at so short a distance from so powerful a radiant. The best test of relative effectiveness would probably be the zonal candle power of the radiant over a specified number of degrees below the horizontal. This is obviously a somewhat unusual and difficult method of testing and the commoner rating by lower hemispherical candle power, which has come considerably into use, is reasonably fair and convenient. The best test of all is the general visibility through the region to be illuminated, not the minimum illumination expressed in candle feet, or the average illumination over a zone, or the apparent brightness of the radiant at a fixed distance, but rather the general impression of useful working light as it forces itself on the attention of an observer used to judging relative illumination. This is a thing for which one could hardly draw a specification, but which is distinctly a function of the intensity of the light given and its distribution. It is not at all a case where photometry would not give a useful result, but rather a case where if one applied the somewhat slow and troublesome photometric processes one would find a condition of affairs which always appeals at once to the educated senses.

Speaking in a general way on this basis, experience shows that the so-called 2,000 candle power arcs can be replaced lamp for lamp with enclosed continuous current arcs taking between 6.5 and 6.75 amperes with, upon the whole, distinct improvement to the general lighting, especially in the lessened intrinsic brilliancy of the radiant. The minimum illumination between lamps will remain about the same; the bright zone disappears; the average illumination over the area is somewhat less, but the visual usefulness—which, after all, is the vital test of general illumination—is distinctly greater with the enclosed arcs, by reason of their less dazzling impression.

With the alternating arcs conditions are not quite so favorable. The 6.5 ampere alternating arc is certainly not the equivalent for street lighting purposes of either the so-called two thousand candle power open arc, or the enclosed direct current arc taking equal amperes with the alternating arc. The latter throws out a little more light far toward the horizontal, but from the effect produced the general usefulness of the light as an illuminant for streets is distinctly inferior. When pushed to about 7.5 amperes, however, the enclosed alternating arc is fully up to the enclosed direct current arc of 6.5 amperes, or thereabouts. Either of the enclosed arcs at 6.5 amperes is superior to the so-called 1,200 candle power open arc. I am compelled, however, to say that the series enclosed arcs, taking in the vicinity of five amperes, are very greatly inferior to those of the ordinary ampereage, and in my opinion, a five ampere direct current enclosed arc is by no means the equivalent for practical illumination of the old 1,200 candle power open arc. With reduced ampereage, both direct and alternating current give a light very strongly bluish and very much inferior in practical visual usefulness to the whiter light of the open arc or the enclosed arc carrying relatively high currents. There has recently been a fairly successful attempt to combat this by the increased density in the carbons, *i. e.*, by using in these lamps with reduced current carbons having considerably less cross section than in the more powerful lamps. This increased density in the carbons produces a salutary effect upon the color of the lamp and renders its use much more satisfactory, although at the cost of somewhat more trouble in renewing carbons.

There has been a great deal of discussion regarding sub-dividing the lights for street illumination, replacing, let us say, 7.5 ampere alternating arcs by an increased number of 5 ampere arcs. This sort of replacement obviously tends to increase the minimum illumination, to lessen the dark spaces between lamps and to give a somewhat lower maximum.

On the other hand, unless the smaller lights are worked with increased current density of the carbons, the quality of the light will be decidedly inferior. Its visual usefulness will also be reduced so as in part to counteract the gain from increased minimum brilliancy of illumination. The lamps also become more numerous, more difficult to take care of, and more costly to install, so that it becomes a practical question for each station to settle for itself on the basis of its costs.

This process of sub-division cannot, however, be carried on indefinitely without getting into trouble from decrease of the maximum illumination; in other words, there will be sufficient light on the street at all points to see to get about, but the general illumination of the street will seem to be and will be comparatively dim. There are cases, as when streets are much shut in by trees, when the ordinary incandescents can be applied with very excellent results, but unless used in great masses they are rather unsuccessful in duplicating the general brilliancy produced by arcs. Between arcs and incandescents proper in point of power, intrinsic brilliancy and efficiency, comes the Nernst lamp, recently introduced. It is too early as yet to speak of its practical usefulness for street lighting, but if its life proves to be satisfactory and its brilliancy holds up reasonably well during its life, I see no reason why it should not usefully meet with many of the requirements of a considerably sub-divided street illumination.

Enclosed arcs and incandescents have the obvious advantage of great steadiness, so that they will probably more and more completely displace the old-fashioned open arc for street lighting as for many other purposes. It may be interesting to note that, in round numbers, it takes in the vicinity of 5 k.w. per mile of street to give a reasonably good illumination.

For general illumination in-doors the requirements are radically changed from those of out-doors. Steadiness and good color form very important considerations. The intrinsic brilliancy of the radiant, if it has a high intrinsic brilliancy, must be cut down, as has already been pointed out, by diffusing globes and shades. In a general way the power of the radiants should, for conditions of greatest usefulness, be proportioned to the area to be illuminated. One could illuminate, for example, a circus tent, an armory or a similar large space with incandescent lamps, but the probabilities are strong that arcs would on the whole answer the purpose better. Contrariwise, one does not ordinarily wish an arc lamp or anything of corresponding brilliancy in one's office. Very brilliant radiants are so objectionable in-doors that the use of shades and globes is imperative, whatever the illuminant chosen. All electric illuminants have intrinsic brilliancy so high as to forbid for hygienic reasons their installation unshaded within the field of view. Even incandescents should be shaded or should have ground or frosted globes, if anywhere within the working field of vision. As has already been pointed out, a diffusing globe on the brilliant radiant improves visual conditions by lessening the glare more than it injures them by reducing the absolute amount of light which gets away from the radiant. Open arcs, as made and used in this country, are generally too unsteady to be worth considering for interior illumination. About their only useful function is in the inverted form, when used for lighting a room by pure diffusion from the walls and ceiling. In every case of interior illumination, diffusion is an important factor in the amount and quality of the illumination. In very high rooms with dark ceilings, or in rooms deliberately blackened, like photometer rooms, the illumination depends chiefly on the light received directly from the radiant. In all ordinary enclosed spaces, however, the illumination measured as such is from one and a half to three times the illumination which can be accounted for by the direct radiation. It is a perfectly easy matter to test this by placing close in front of a powerful radiant a small opaque disk and observing the very considerable illumination within the shadow of this disk due to the light diffused from the walls and ceiling. The shadow may appear dense, but there will be, nevertheless, a considerable amount of working illumination even within the shaded area. The presence of this diffusion has two very important effects.

In the first place, it lessens the energy needed for the radiant to produce a reasonable amount of general illumination.

Secondly, it renders the distribution of light from the radiant practically a matter of indifference, providing this distribution is not eccentric in some remarkable fashion.

Both of these facts are of great practical importance in planning illumination, both as to kind and amount. Further than this, the color of the diffusing surface often has an important bearing on the general color value produced by the illuminant used. If one desires to judge colors as they would be judged in daylight, it is necessary not only that the radiant itself should give light near to white, but that the diffusing surfaces, which co-act with it in producing the general illumination, should not be strongly colored.

A well-shaded open arc gives a close approximation to daylight color values. Next to it comes the Nernst lamp and incandescent lamps worked at high efficiency—three watts or thereabouts per candle. Next to these come gas jets of the ordinary kind and enclosed arcs worked with fairly large current; the former erring somewhat on the side of yellow and the latter on the side of blue. The obvious moral is, when using enclosed arcs provide at least one globe with a slightly yellowish coloration, which reduces the enclosed arc to a parity with the open arc in the matter of color values without serious loss of brilliancy.

Finally, at the foot of the list come Welsbach lights and low current enclosed arcs. Neither of these should ever be used where color values are an important consideration without elaborate shading to suppress the dominant green and blue tinge, of the respective lights. Since all of these radiants should be shaded for interior work, it is easy to apply such corrections for color by the use of tinted shades, although in some cases the loss of light by this procedure might prove objectionable.

For all this work of general illumination in-doors, the quantity which determines the total useful luminous effect is, with rare exceptions, the total luminous flux and not the flux in any one particular direction. It is the total luminous flux that determines the amount of light available, both for direct illumination and for the diffusion that is scarcely less important. The ordinary observer has no conception of the efficiency and artistic value of diffusion in securing general interior illumination.

Those of you who chanced to attend my lecture early last year before the New York Electrical Society, will perhaps recollect the wonderfully effective diffused illumination; thanks to Mr. Lieb, in whose precinct the lecture was given, it was possible to secure by the use of 32 c.p. incandescents in the frieze around the upper part of a high hall, where practically the whole diffusion came from the ceiling.

Radiants which, on the score of high intrinsic brilliancy or even bad color would scarcely be permissible for direct use, can be used with great effect in producing a purely diffused illumination. I lay stress upon the importance of diffusion, because it not only wipes out the sometimes annoying differences of distribution between different radiants, but also because the development of diffused lighting gives promise of obtaining artistic results, which can hardly be secured in any other way.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

STREET ILLUMINATION AND UNITS OF LIGHT.

BY W. D'A. RYAN.

PHOTOMETRY.

In order to make photometric comparisons of open and enclosed arcs, I have found it necessary to work as far as possible with fixed conditions such as current, voltage and position of arc. The widely different results of various investigators are in part due to insufficient attention to these essential points, particularly the latter. A photometer with a reasonably long bar is also indispensible. This should be provided with an adjustable revolving sector disk by which the light from the arc can be reduced so that all settings can be made in the most accurate part of the scale. This arrangement permits working with a single standard and with light of low intensity which decreases the error introduced by color difference. A rotating crane is required for elevating and depressing the lamps in order to measure the light from different angles in the vertical plane.

A Bunsen photometer as described can be operated by three observers, but I have found four more satisfactory; one devotes his time entirely to making settings of the screen, the second maintains the current and voltage at the proper values, the third notes the position of the arc, and the fourth records the readings taken when the fixed quantities are correct. After working together for a few days, such a complement can reproduce the average characteristics of light distribution of arc lamps to within 5 or 6 per cent. of the mean which, for arc lamp photometry, is considered very satisfactory.

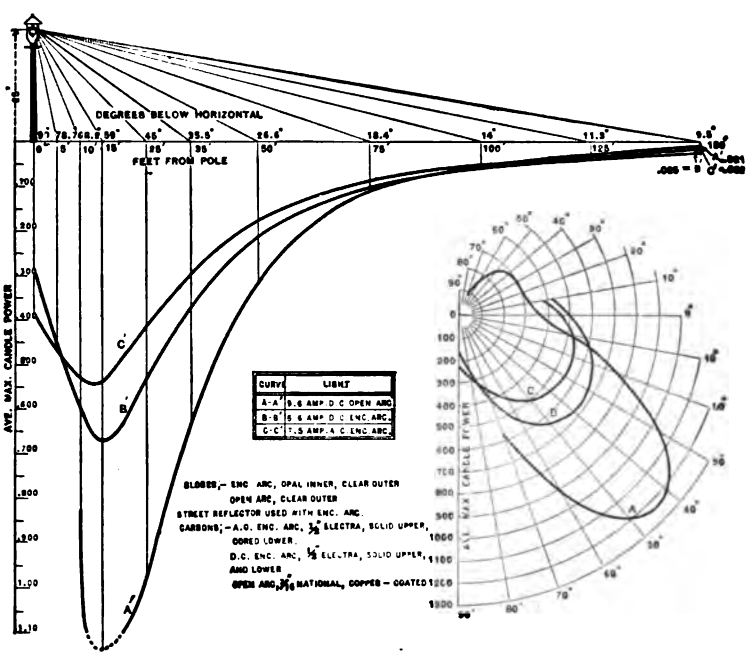
CANDLE POWER CURVES.

The curves in Fig. 1 were obtained by the method described.

To render the curves of commercial value the tests were carried on with lamps equipped as they ordinarily would be for street lighting, that is to say, the open arc lamp was trimmed with 7/16″ National carbons and was provided with a clear globe.

The enclosed arc lamps were trimmed with high-grade carbons and were provided with opal enclosing and clear outer globes and street reflectors. All lamps were adjusted so as to consume approximately equal watts at the arc.

First confining our attention to the direct current lamps,



Street Illumination Curves. Candle Power Curves.

Fig. 1

curves A and B, we will observe that the open arc lamp gives a greater maximum candle power (which, of course, is not by any means a measure of its usefulness). The enclosed arc lamp gives a stronger light through the most useful angles of from say 3° to 10° below the horizontal and from the shape of the curves it is self-evident that the distribution from the latter is more uniform.

Illumination Curves.

We are not, however, particularly interested in the candle power of the lamps. We desire principally an even illumination along the street surface, and we wish mainly to project the light as far from the source as possible.

To make this comparison, it is therefore necessary to convert the "candle power curves" into "illumination curves" giving the candle feet along the ground on surfaces normal to the rays of light.

The illumination curves in Fig. 2 are plotted for lamps 25 feet above the ground and at intervals of 300 feet. By introducing the element of distance we find that the strongest light received on the ground fro.n the open arc is not projected at an angle of 45° as indicated by the candle power curves, but falls at an angle of about 60° below the horizontal, illuminating the ground brilliantly at a distance of about 15 feet from the pole, thus showing that in order to properly compare illumination of different lamps we must look to the surface illumination curves rather than the candle power curves, as previously stated.

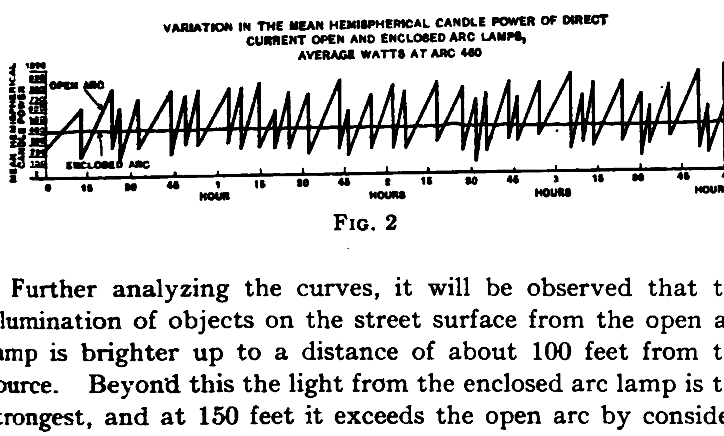


FIG. 2

Further analyzing the curves, it will be observed that the illumination of objects on the street surface from the open arc lamp is brighter up to a distance of about 100 feet from the source. Beyond this the light from the enclosed arc lamp is the strongest, and at 150 feet it exceeds the open arc by considerable, and this is made still more effective by the absence of strong light in the immediate vicinity of the lamp. This advantage is so obvious that further comment seems unnecessary.

Comparisons so far have been confined to fixed conditions with respect to current, voltage and the position of the arc.

We have next to consider the variations caused by the wandering of the arc, variations of potential between picking up and feeding points, fluctuations due to drafts of wind, non-homogeneity of carbons and other changes introduced by the inherent peculiarities of the different lamps.

VARYING ARC.

Open arc lamps ordinarily pick up at about 45 volts and feed normally at about 50. The light projected in any direction is approximately proportionate to the amount of crater area visible from any point in that direction, and the amount of crater area visible varies greatly with the small change in the length of the arc introduced by a difference of 5 volts.

Where lamps have been installed for a considerable period and have not received proper attention, the voltage variation may greatly exceed the normal limits. The lamp is then said to be working between a sluggish feed and the hissing point, and as

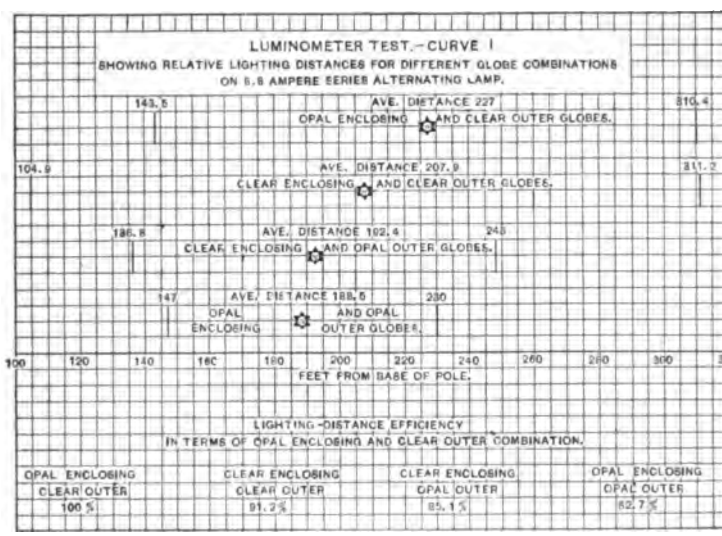


FIG. 3.

the arc feeds on an average cycle of about ten minutes, varying irregularly between 5 and 15 minutes, the candle power and illumination shown in Figs. 1 and 2 represents only instantaneous values which occur at very irregular intervals.

The enclosed arc lamp is particularly free from this variation. The arc is about $\frac{3}{8}''$ in length and the lamp feeds in about 4-hour cycles, varying irregularly between 3 and 5 hours, and the feed is an instantaneous drop and pick up to the original position. There is, however, a rise of voltage due to the heating of the shunt coils which may amount to 10 or 15 volts. This is a gradual rise, taking place during two or three hours, and is not noticeable as a variation to the casual observer. It is objectionable, however, for other reasons. In some lamps this variation is con-

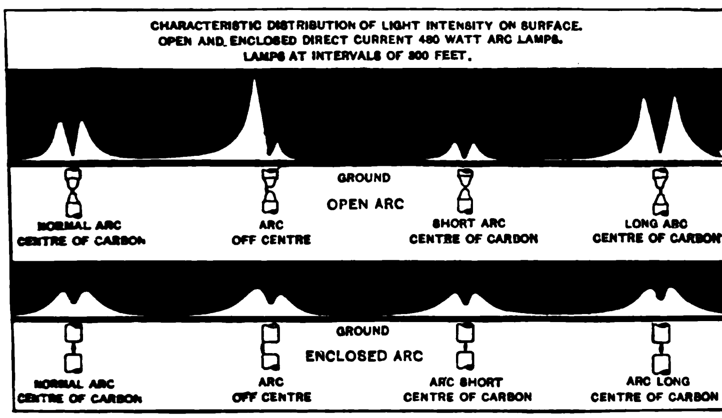


FIG. 4.

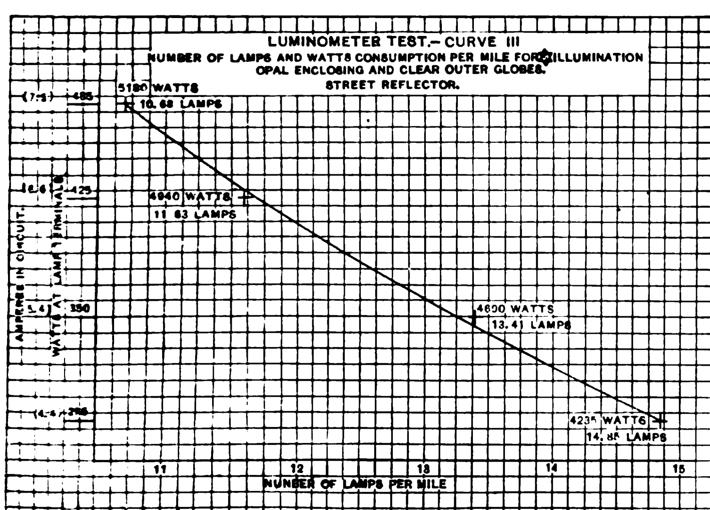


FIG. 5.

trolled by what is called a " compensating winding " which automatically adjusts the relation between the shunt and series coils as the lamp heats up.

For such lamps we may say that the mean hemispherical light is practically constant, as the voltage at the arc does not materially change. Thermostats have also been employed to accomplish the same result, but they have not proved entirely satisfactory, and in some localities they require a summer and a winter adjustment.

Wandering Arc.

The second variation of importance in open arcs is caused by wandering of the arc, due primarily to the non-homogeneity of the cheap grade of solid carbons usually employed. When the

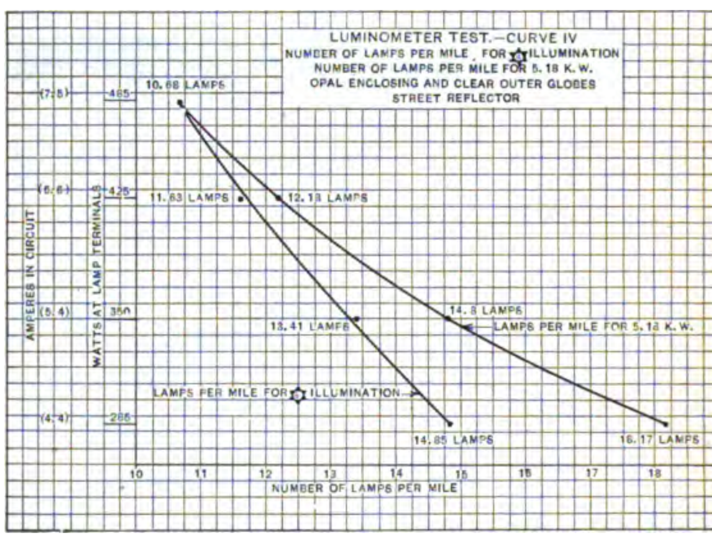


Fig. 6.

arc travels to the edge of the carbons we have a great volume of light from one side and very little from the opposite side.

Under such conditions the photometer would probably show a freak reading of 1,600 to 1,800 maximum candle power from a lamp which would give about 1,200 when the arc is co-axial with the carbons.

This wandering also takes place in the enclosed arc lamp, but it is not due particularly to the non-homogeneity of the carbons, because a high grade of carbon is employed, but it is primarily caused by the carbons burning flat in a globe practically free from oxygen and the arc wanders of necessity. The variation in the light from this cause is not so great as in the open arc, but it is not altogether pleasant when clear globes are employed.

By using an opal-enclosing globe, the light is balanced and the variation is reduced to a satisfactory degree of steadiness and all shadows are obliterated (Fig. 3).

Flickering Arc.

A common complaint against the open arc is the flickering due in a measure to non-homogeneity of carbons, but mainly to the wind blowing the arc about. While the latter cause is not inherent in the arc, it is common practice in America to leave the arc exposed to the wind and as this condition exists it seems reasonable to include it in the comparison.

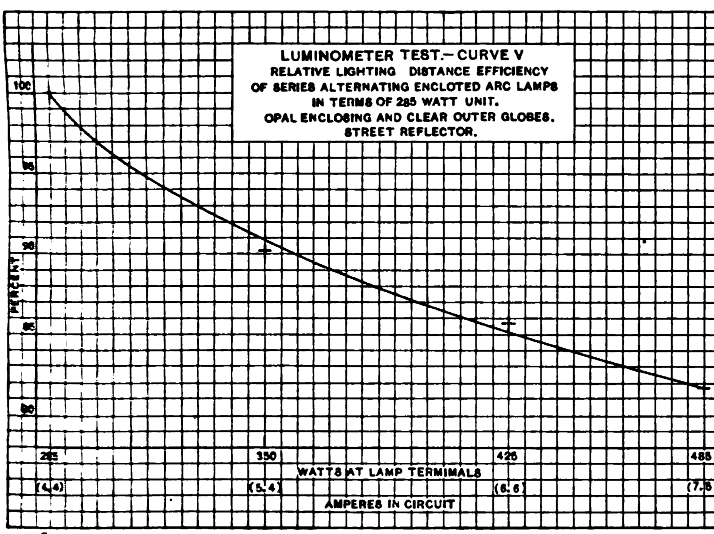


Fig. 7.

High grade carbons are employed in the enclosed arc lamp and the arc is thoroughly protected from the wind so that flickering from the above mentioned cause is entirely absent.

Alternating vs. Direct Current Arc.

We are all more or less familiar with the low light-giving efficiency of an alternating open arc lamp. By the introduction of the enclosed lamp with its long arc and opal globe, the difference in lighting efficiency between alternating and direct current has practically disappeared, so that the alternating enclosed arc has about the same illuminating value as a direct current enclosed arc of equal watts.

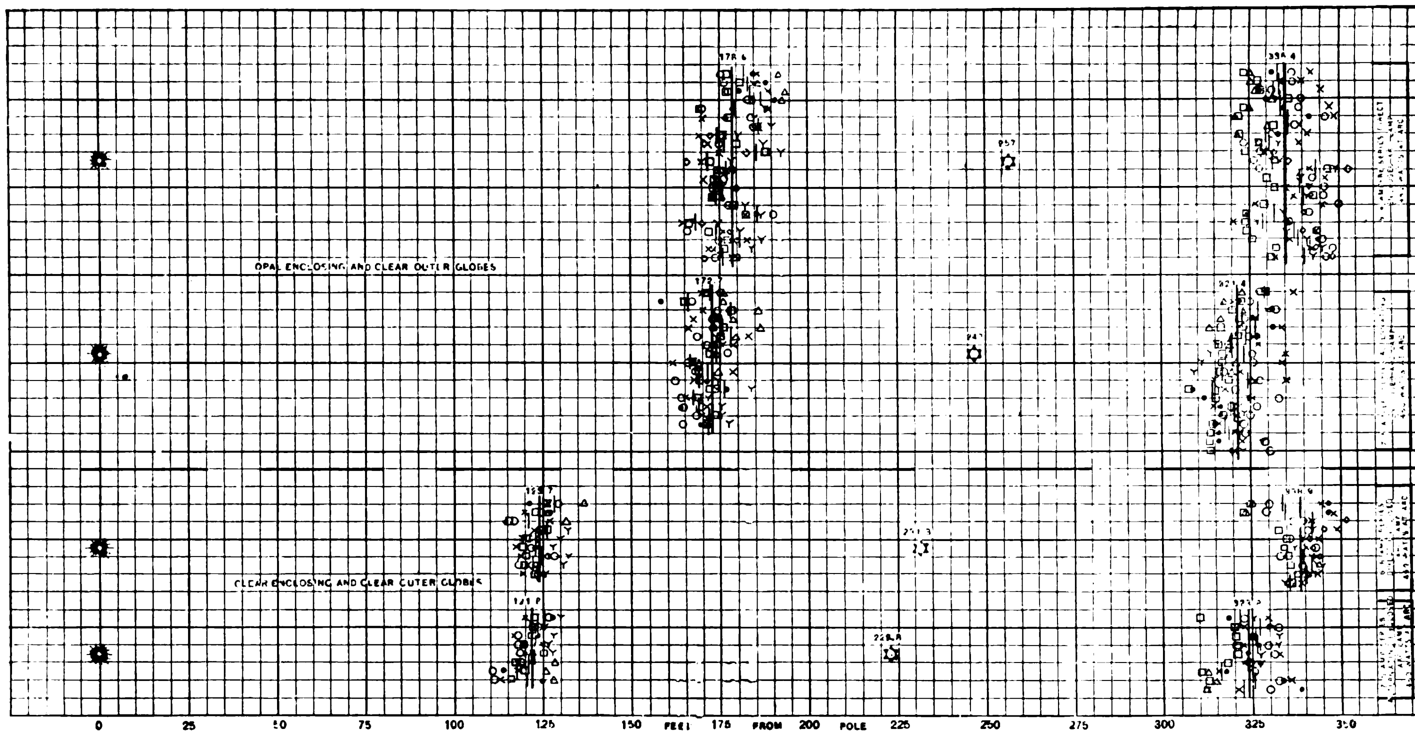


Fig. 8.—Luminometer diagram indicating that alternating and direct current arcs of equal energy will illuminate practically the same distance (Advantage of opal Enclosing globe).

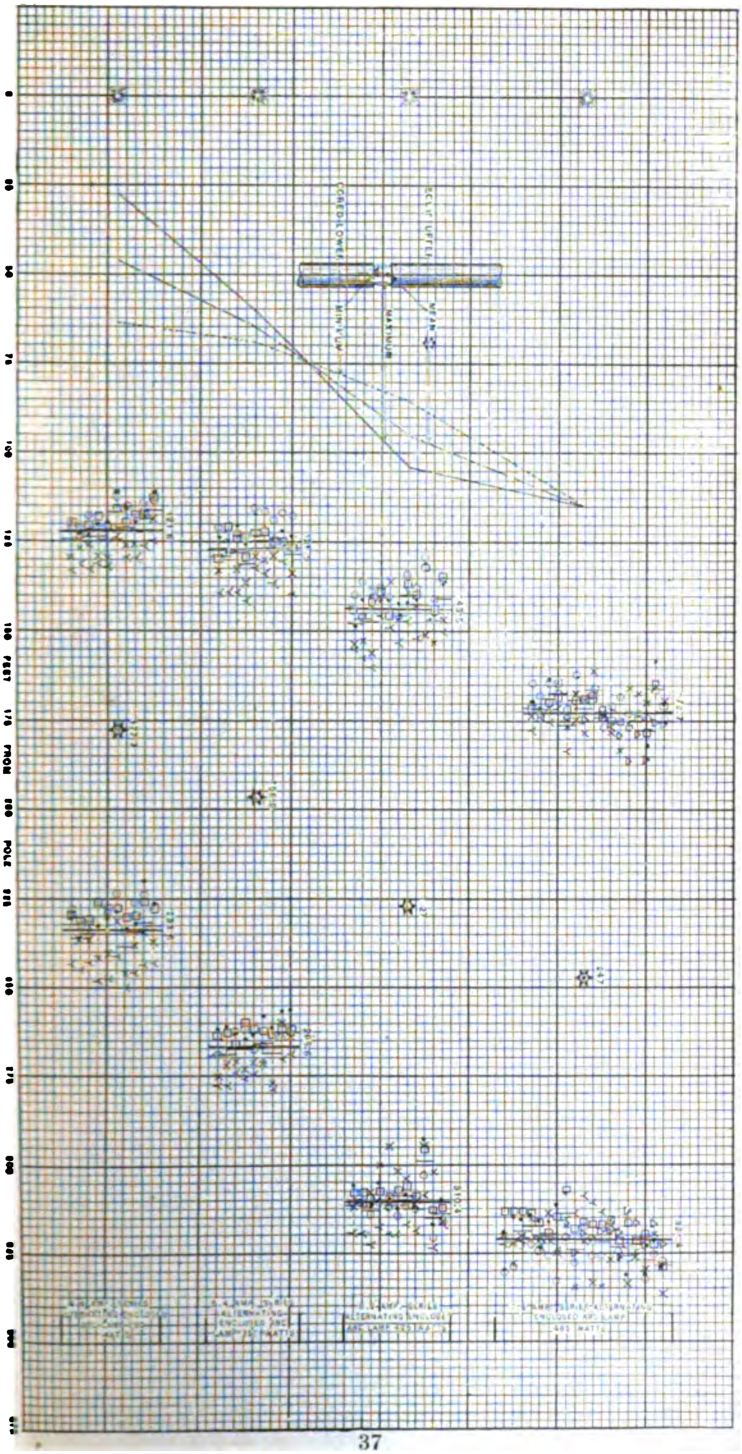


Fig. 9

It will be observed from the curves that the alternating arc does not give so high a candle power in any direction as the direct arc, but the distribution is slightly better and the effective illuminating value of the two lights at a point midway between lamps is about equal.

Small vs. Large Units.

In lighting a street we strive to light it uniformly so as to approach a moonlight effect. The employment of small units towards this end forms the basis of a most interesting investigation.

A photometer cannot be relied upon to give sufficiently accurate results for such comparisons, but I have found a small instrument called a " luminometer " very satisfactory. This instrument, while not a scientific piece of apparatus, is of considerable practical value, and it is used to determine the maximum distance a lamp will project a given illumination. A standard illumination of .006 of a candle foot was adopted throughout the tests. For convenience this was designated " star six illumination," and this convention is employed in all the diagrams. Tests taken on different nights and with different observers checked within 2 or 3 per cent. of the mean, and the results can be relied upon as being sufficiently accurate for all practical purposes.

It is quite impossible to lay down a fixed rule for the number of lamps which should be installed per mile, as the location is determined largely by the distance between cross streets, the amount of light required and other local conditions.

Nevertheless, data on the relative lighting distance of various units can be used to advantage.

The accompanying diagrams show the relative lighting distances of 285, 350, 425 and 485-watt alternating enclosed arc lamps. The lighting distance efficiency of these lamps in terms of the smallest unit is respectively 100, 90.2, 85.7 and 81.7 per cent.

For " star six illumination " midway between lamps, we would install 10.7—485 watt units or 14.9—285 watt units per mile.

The former would consume a terminal wattage of 5,180 and the latter 4,235. resulting in a saving of nearly 1,000 watts per mile with the advantage of four more brilliantly illuminated areas in the interval. Further, for 5,180 watts per mile we could install 18.2—285-watt units which would give us relatively eight

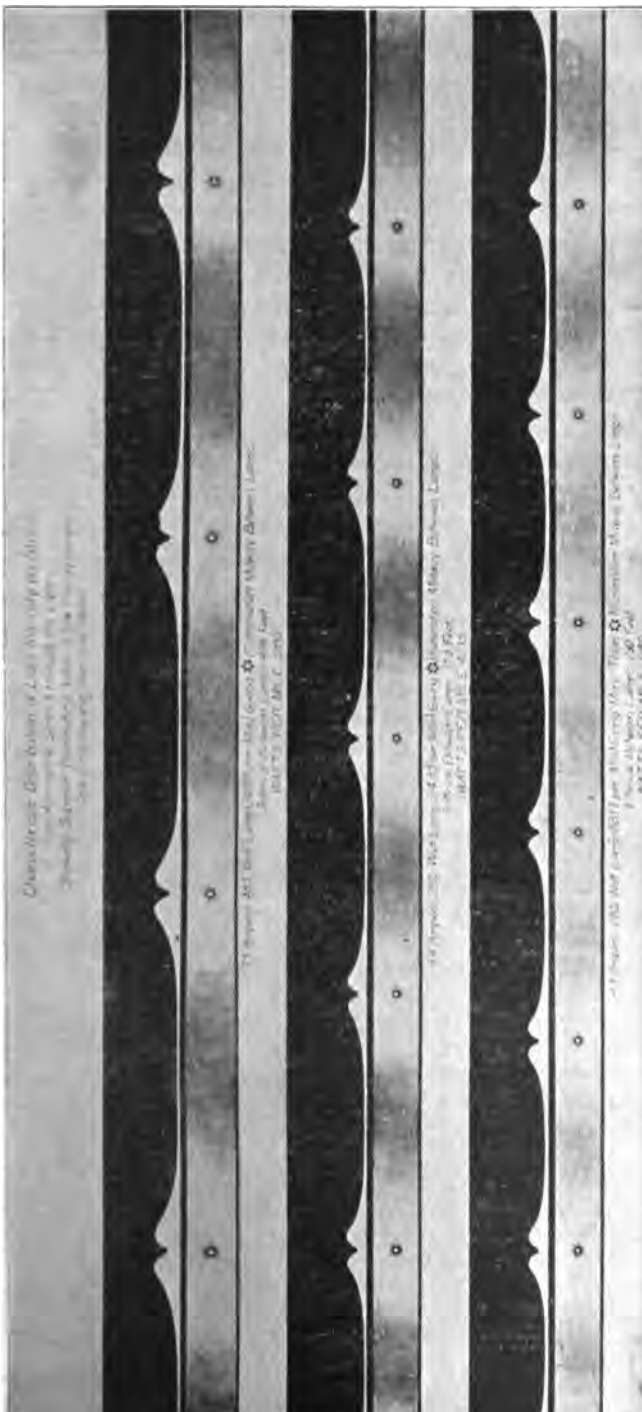


FIG. 10.

more brilliantly illuminated areas in the interval, for the same expenditure of energy and with more than star six illumination midway between lamps, therefore, from a light distribution point of view, the advantage of the small unit is established.

While I am not prepared to state that a 285-watt lamp is the lowest practical arc unit, still I believe that this is about as small as can be satisfactorily operated for street lighting. I can say, however, that the argument for small units does not apply to incandescent lamps, because one of the essential requirements for good lighting is the illumination of buildings and other objects on the street to a considerable height above the ground. This requirement is fulfilled by arc lights which flood the buildings with light and thus produce a general diffusion, giving the street an illuminated appearance impossible to obtain with incandescent lamps, even when placed very high, and at such short intervals as to make their use prohibitive from a point of economy. Moreover, the light from incandescent lamps in common with all comparatively low temperature sources lacks the luminosity or brilliancy obtainable from the electric arc, and it therefore cannot encroach upon the arc where a considerable volume of light is required, although it fulfills in a very satisfactory manner a street lighting field essentially its own.

From the foregoing we draw the following conclusions:

First:—Open arcs give a higher maximum candle power than enclosed arcs of corresponding wattage, but the maximum candle power is in an undesirable direction, and the light fluctuates through wide limits. Enclosed arcs give a higher candle power through the most useful angle, from say 3 to 10° below the horizontal. The light from the enclosed arc is more uniform and steadier and generally superior from an illuminating point of view to open arcs.

Second:—Direct current enclosed arcs produce slightly higher candle power than alternating enclosed arcs of corresponding wattage, but so far as the illuminating value is concerned, the two lamps are on a fair basis of equality, both being superior to the direct current open arc.

Third:—Small unit arcs will illuminate proportionately greater distances than large units for a given expenditure of energy.

Fourth:—Incandescent lamps do not illuminate brilliantly to a sufficient height above the street surface to produce the effect of good lighting, and are therefore not comparable with arc lights.

In justice to the open arc, I wish to state that if we follow European practice, as carried out in large cities, of installing lamps at short intervals, say 80 to 175 feet apart and use more complicated lamps which work within closer limits when carefully attended to, burn high grade carbons, protect the arc from the wind and use opal globes, the advantage of the enclosed arcs over open, from a light distribution point of view, will somewhat disappear.

Aside from the mere question of light however, there are other arguments for the enclosed arc, particularly with reference to maintenance, convenience and cost of operating, which would throw the balance in its favor even if the open arc were raised to an equal illuminating plane.

A paper presented at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3rd, 1902.

SOME COMMON FAULTS IN EXTERIOR ILLUMINATION.

BY S. EVERETT DOANE.

General illumination may conveniently be considered from two points of view:

First—The actual distribution of light to the object illuminated.

Second—The value of this illumination to the observer.

We can accurately express the value of the first, but can speak only in general terms of the second. Much has been said about the first and but little about the second, yet the second is the practical end for which all illumination is designed. Whether or not the source of light is in range of the observer's vision largely influences the second value.

The contrast between the source of light and its environment is all important. A farmer's barn lantern will completely blind one to the road beyond when the night is black, and the vicinity not otherwise illuminated, whereas an arc lamp backed by a white building may be a fairly satisfactory source of light.

I had occasion during many of the evenings last summer to ride over the country roads near my home, and I had plenty of opportunity to notice their illumination. It was my observation that the best lighted towns in my vicinity used kerosene lamps situated at the side of the roads among the tree trunks.

Many and many a time when riding toward an arc lamp have I kept my place on a highway by guiding myself by the shining rail of the street railway track, absolutely unable to tell from the roadbed of shadows what was before me. Actual observations of this character make it clear that the amount of light actually delivered to a roadbed is only a part of what we must consider.

If the source of light must from its character be so placed that the observer is blinded to the road, it avails little as to the candle-power of that source. An arc lamp usually must be so placed that its light may shine in one's face in order that the light may shine along the road.

Light delivered from a lamp near at hand is much to be preferred to light delivered from a lamp so far away that the rays of light reach the ground at a small angle. Such light magnifies every hummock and equally shadows insignificant hollows and gulleys deep enough to be dangerous. It would be better to have half the illumination and be able to see the bottoms of the hollow spots. One of the recent papers on arc lamps spoke of their value in illuminating the houses and trees, and presumably the landscape, where there are no houses and trees.

The interest in this observation lies in the thought that the greater the candle power, and the more infrequent the lamps, the smaller is the portion of the total light shed upon the ground which actually reaches the roadway.

The Massachusetts State roads are uniformly 20 ft. wide. The country roads rarely exceed 30 ft. in width. City roads of Massachusetts are required to be 40 ft.

Arc lamps, located respectively 200 ft.,300 ft. and 400 ft. apart, are evidently intended to illuminate plane areas about 31,500, 70,000 and 125,000 square ft. in extent.

A 20 ft. road crossing this area will receive about 12.7 per cent., 8.6 per cent. and 6.4 per cent. respectively of the light delivered to the ground.

A 40 ft. road will receive twice this percentage, of course, but as the 20 ft. width is all the average rider ever notices, the illustration will answer. From this it is very apparent why it is wise that lamps of reduced candle power be placed closely together.

From this same illumination it will be seen that lamps placed 200 ft. apart, consuming one-half the energy, may be of one-half the efficiency and still give equally efficient illumination and, what is more to the point, will deliver their light from a more advantageous direction.

One of the best illustrations of suburban street lighting by arc lamps which comes to my mind is on the Boulevard from Boston to Auburndale. The Boulevard is really two separate roads with a continuous narrow park between, and the arc lamps are in the middle of this park, so that they may be said to be in a field adjoining the roads. Why, with all these draw-backs, are arc lights used almost universally and incandescent lamps to so limited an extent?

I think there will be no discussion as to the reason. Incandescent lamps for street lighting have always been difficult to make, and less satisfactory than any other type of incandescent lamp.

The ordinary 100-volt to 125-volt 16 c.p. 3 l.w.p.c. incandescent lamp gives more candle hours for a given input than any other incandescent lamp. If this lamp could be used for street lighting the cost of street lighting by incandescent lamps could be materially reduced and the service rendered be much more satisfactory to the user of the highway.

There are many streets in which low voltage mains run the length of the streets and where these lamps could be used in multiple with no inconvenience. There are many other streets where ten or twenty could be used in series, each on a cut-out box, no more complicated than the Nernst lamp, which you will possibly be called upon to consider. These cut-out boxes would not be so complicated as the arc lamps, which operate with practically no attention. I do not understand why this has not been done.

Times have changed. The arc lamp lines are no longer the only wires on the poles. Probably one-half of the electric lighting poles carry alternating current mains also. Incandescent lamps are now universally fastened to their bases by a waterproof cement, and waterproof sockets are in stock everywhere. Is it not time that we broke away from tradition?

The arc lamp has its use in street lighting. There are places where it is wisest to use it. The public think they are getting more for their money with the brilliant arc lamp, but I believe that as the users of the highways come to appreciate how much safer and more satisfactory well-placed illumination is than that to which I have referred, we will learn to light our streets as we do our homes. The lesson learned in show-window lighting and in theatre stage lighting should not be lost upon us. It is not the light, after all, that interests us; it is what we see by means of the light.

We must add to this that for a given expenditure of energy more light can actually be delivered to a highway by incandescent lamps than by arc lamps and it can be better distributed.

Arc lamps are at their best in densely settled districts. The reflected light from buildings helps to economize the distribution, and the great quantity of light from store windows also assists so to brighten the surroundings that the brilliant arc lamp is less blinding. Arc lamps are also more closely spaced in these localities, which is to their advantage.

Incandescent lamps are, in my opinion, much to be preferred for residential streets, side streets and outside the more congested portions of a town or city.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

THE INCANDESCENT LAMP OF TO-DAY.

BY JOHN W. HOWELL.

The incandescent lamp is too well known to you all to need an introduction or any description. It has been so often discussed before you that nothing remains to be said about it except as a part of the electric lighting system in the general discussion of the subject under consideration this evening.

The characteristic features of the incandescent lamp are its extreme simplicity, its absolute freedom from mechanism, the ease with which it can be lighted by means of a switch placed where most convenient, and its adaptability to low candle units and decorative effects. These features and the fact that it consumes no oxygen, yields no gases and has no flame, have won for the lamp its great popularity.

The incandescent lamp is adaptable to any system of electrical distribution in use for any purpose. There appears to be no difference in its operation on direct or alternating current, provided the latter has a frequency of 25 cycles or more per second. It is usually operated on constant voltage circuits, but gives even better results when operated at constant current, as the increase in resistance of the filament with use increases the watts consumed, and thus causes the lamp to maintain approximately its initial candle power throughout its life.

For street lighting, incandescent lamps are operated many in series on high voltage circuits of constant current. They are also made for burning directly in series with arc lamps.

The incandescent lamp is adaptable to those voltages which are generally considered safe for interior use. Two kinds of carbon are used in making filaments and the best results require the proper combination of the two kinds. The specific resistance of these two kinds of carbon limit the voltage of lamps of a given candle power and efficiency in which this proper combination can be made.

Lamps for a higher voltage than will permit the proper combination of the two kinds of carbon may be made with less of the graphitic coating which has a low specific resistance, or entirely of the base carbon, but in either case the lamp should be operated at lower temperature to give equally good life and candle power results.

The best results are obtained with lamps of not higher than 120 volts—250 volts being now regarded as the maximum desirable voltage, and at this point there is an increase of about one-half a watt per candle for equally good results.

The efficiency of an incandescent lamp depends upon the temperature of the filament—the higher the temperature the better the efficiency and the shorter the life. Lamp efficiencies are usually stated in watts consumed per horizontal candle. The commercial limits are between 2½ and 4 watts per English candle, or about 120 per cent. of these figures if spherical candle power is considered, the 2½-watt lamp being used where electricity is expensive and regulation good, and the less efficient lamps where electricity is less expensive or regulation is not so good, or where other considerations demand a longer useful service from the lamps.

The color of the light from an incandescent lamp depends entirely upon the temperature of the filament, the higher the temperature the more nearly white the light becomes. The color of the light generally is yellow. Weber observed that the first visible radiations from a filament as it was heated came not in the red region of the spectrum, but in the yellow region, where the maximum radiation occurs when the lamp is at high temperature.

Dr. Nichols observed that carbon has a selective radiation in the yellow region of the spectrum, the radiations there increasing faster than radiations in the other parts of the spectrum.

The use of higher efficiency lamps is becoming quite general, very few 4 w. P. C. are now used for multiple lighting, while a few years ago no lamps of less than 4 w. P. C. were sold. This is due to the improvement in quality of the lamps and also to better regulation of current. High efficiency lamps are more satisfactory than low. The filament being smaller, the bulbs blacken less, and being hotter they break before reaching very old age. Low candle power lamps are also coming into more general use. The demand for these has increased very considerably in the last two or three years. The use of lamps for decorative effects and for special work of various kinds has increased the usefulness of the lamp and added to its popularity.

HARRISON, N. J., December 7, 1901.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

A NOTE ON AN ACETYLENE-IN-OXYGEN FLAME.

BY CLAYTON H. SHARP.

In the conclusion of a report made to this INSTITUTE in 1896 by a sub-committee on Standards of Light of which Professor Nichols was chairman, it was stated that the sub-committee had in hand the investigation of a possible standard in which a pure gas, burning in a pure atmosphere should furnish the constant flame required. Since these investigations, which were being carried on by myself, have now been at a standstill for some time, this note is presented with the hope that it may be of some interest.

The idea underlying the work was to produce a flame which should be isolated from fortuitous outside influences, such as atmospheric purity and moisture content, which have so large an influence on ordinary flames.

A long series of experiments was conducted on a flame produced by the combustion of a mixture of equal parts of acetylene and hydrogen in an atmosphere of oxygen. The special burner employed gave a flame long, slender and of great brilliancy and steadiness. It was found, however, that its intensity was not reproducible from pressure measurements made on the gases. This was attributed to the fact that the acetylene-hydrogen mixture was stored over water. Since the solubility of these gases in water is not equal, and their temperature coefficients of solubility are not the same, the relative proportions of the two gases in a mixture so stored would not remain constant. Thus, the first requisite of a standard of light, namely, a fuel of perfectly definite composition, was lacking.

The reason for adopting the acetylene-hydrogen mixture instead of pure acetylene as a combustible had been that, with the burner employed, pure acetylene deposited graphitic carbon about the jet with such rapidity that the flow of gas was seriously obstructed after only a moment's burning. With the diluted gas this did not take place. After the failure of the mixture to yield the constant flame required, experiments were made to determine what form of burner would permit the pure acetylene to be used. This was found to be as shown in Fig. 1.

The acetylene passes through the tube A, which is surrounded by the water-jacket J, in which a circulation of water is maintained to keep the acetylene tube cool, and issues at *a*. The

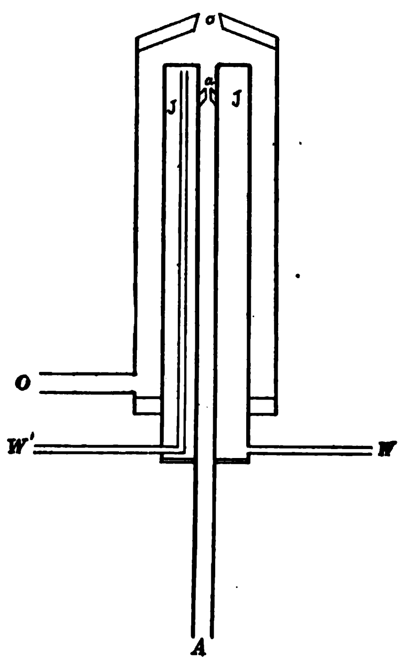


FIG. 1.

oxygen enters at O, a concentric tube and issues through o in a stream about the stream of acetylene. The water-jacket is carried above the acetylene jet so that a mixture of the two gases, and consequently combustion takes place only after the acetylene is well away from the jet from which it issues. With this arrangement there is no troublesome deposit of carbon and the experiment can be carried on indefinitely.

The flame so produced is capable of enormous variations, according to the relative supplies of the gases. When the oxygen is not turned on at all, the flame is tall, unstable, murky and smoky. With increasing supply of oxygen, the flame shortens and increases in whiteness, brilliancy and luminous intensity. It also becomes stable and is little affected by drafts. If the increase in oxygen supply is carried beyond a certain point, the luminous intensity begins to fall off, due to the non-luminous combustion of a larger proportion of the acetylene, until with a large excess of oxygen the flame becomes almost entirely blue.

Barring practical difficulties, the intensity of this flame should be definable as follows: with a given rate of flow of the gases, the height of the flame should be a given one, and the luminous

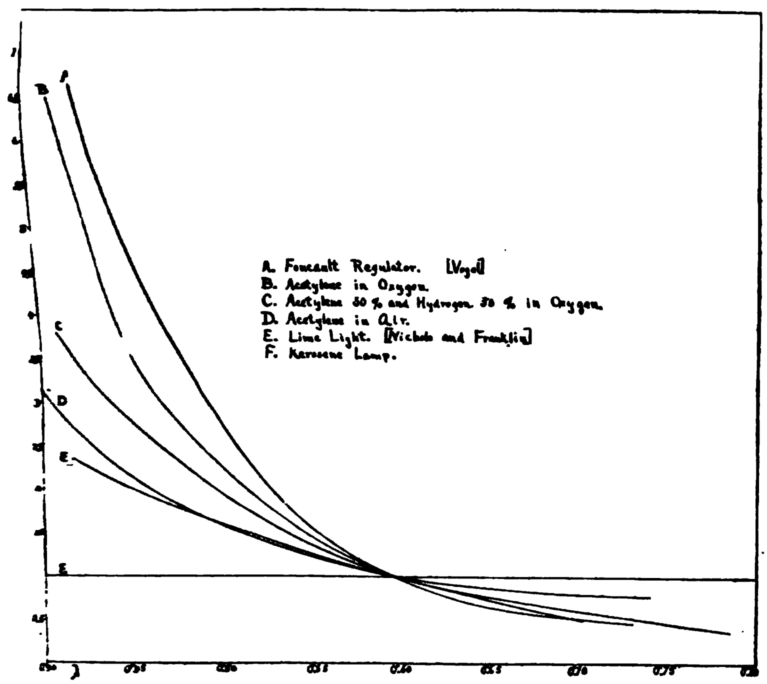


FIG. 2.

intensity of the flame as a whole should be a maximum, and the luminous intensity of a portion of the flame isolated from the rest by a horizontal slit of a given width in a screen placed in front of the flame in such a way that the amount of light passing through the slit should be a maximum, would then be perfectly fixed. The criteria mentioned are not all independent ones, but serve as checks on each other, and increase the certainty with which the flame can be reproduced.

In my experiments I measured the height of the flame by projecting an image of it on a graduated screen. To measure the flow of the gases a diaphragm with a very small opening was interposed in each feed pipe and the gas pressure behind was determined by inclined tube manometers filled with alcohol. This method was not found to be sufficiently sensitive and reliable. It would probably be far better to fix the relative pressures of the gases by passing them through small gasometers, the bells of which are fixed to opposite arms of a balance, as Petavel[1] has done in his experiments with the Violle platinum standard, and then to determine with only a moderate degree of accuracy the absolute pressure of one of the gases. The gas supply was regulated by micrometer cocks. The temperature of the diaphragms should be controlled and the gases should be dried.

The flame so produced is the most brilliant gas flame known. The results of spectrophotometric measurements on it are shown in Fig. 2 in comparison with those made on other sources of light. Its color adapts it admirably for use as a secondary standard in arc light photometry, but it is too white for the incandescent lamp, just as the candle and the Hefner lamp are too red. This fault is at least in the right direction, since it is desirable that the color of the primary standard of light should approximate to the color of the average source of light in practical use, and the constant tendency of this color average is towards the white.

1. Proc. Roy. Soc. Vol. LXV, p. 481, 1900.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

THE PRESENT STATUS OF THE QUESTION OF A STANDARD OF LIGHT.

BY CLAYTON H. SHARP.

The situation as regards a standard of luminous intensity has shown in recent years a marked tendency towards simplification and unification. A number of standards or would-be standards, which were formerly taken seriously, have disappeared from practical use. Of the various candles, the British candle is the only one which survives, and the practical use of it is steadily decreasing. The Carcel lamp is held in much less esteem than formerly. Practice is settling down to the selection of one of two classes of standard, either the pentane standard in one of its forms, or the Hefner amyl-acetate lamp.

The small 1 C. P. and 1½ C. P. pentane lamp has proven itself worthy of confidence as a result of thorough investigation in the Reichsanstalt. The 10 C. P. pentane lamp is coming into very extensive use by the gas men here and in England, and commends itself by its simplicity of operation, by its relatively high intensity and, as far as is known, by the constancy of its indications. Unfortunately there is on record no such careful investigation of its properties in this particular as has been made for the smaller pentane lamp and the Hefner lamp.

If gas practice is looking more and more to the pentane standard, electrical practice is looking towards the Hefner lamp. The careful study made in the Reichsanstalt, the adoption of it officially in Germany, the resolutions in its favor by this INSTITUTE and by the Geneva Congress of 1896 have served to popularize it and to intrench it strongly.

While the facts enumerated show that great progress has been made, it is not to be assumed that a satisfactory solution of the problem of a standard has been reached. A standard must be as nearly as possible a common denominator of the sources of light in ordinary use. No one integrated source of light can be in all strictness a common denominator for all, on account of the existing differences in quality or color. That light most nearly fulfills this condition which most nearly approaches in color the average color tone of the sources of light in use to-day. Now this is much higher than it was a few years ago, due to the extensive introduction of whiter hued sources of light. The standards referred to above, stand as far as color is concerned, about at the bottom of the list, and from this point of view are as bad as possible. Photometric comparisons with them of most modern lights are very uncertain, and the results are misleading in that they do not give to the whiter sources credit for the greater visual acuity per candle power which is their due.

It follows that a standard of light of considerably whiter hue than the present ones would be intrinsically better if of equally good qualities in other respects, and it is towards the definition of such a standard that efforts should be directed.

Quite a good deal has already been done in this line. A notable advance has been made by Petavel[1] in his investigation of the Violle platinum unit. He has indicated the precautions which must be taken to secure good results, and has demonstrated that the limits of error may be made quite narrow. The color of this standard is quite good. Violle has stated that it is very similar to that of the acetylene flame, but this statement does not seem to be entirely consistent with the known fact that platinum can readily be fused in the acetylene flame.

The studies by Paschen and by Lummer of the theoretically "black" body have indicated a method by which a perfectly definite radiating surface can be secured, and it needs only a sufficiently accurate method of defining the temperature of such a surface to give us a standard of light. Since, however, the luminous radiation from such a surface increases as a high power of the temperature, a sufficiently accurate method of temperature definition cannot easily be found.

Among the ordinary sources of light, the acetylene flame probably approaches most nearly in color to the average hue. The ease with which this gas can be produced in a good degree

1 Proc. Roy. Soc., Vol. LXV., p. 481, 1900.

of purity and the steadiness and manageability of its flame also commend it for use as a standard. Violle[1], Fessenden[2] and Féry[3] have made independent propositions to this end, but no definite standard as yet been the outcome.

Fessenden showed how a stable flat flame can be produced with this gas, employing the method of the converging jets now in common use. He found the flame to be very steady and moderately immune from outside influences. Such a flat flame, with the light from its edges screened off, has been used very successfully by Professor Nichols[4] in his spectro-photometric investigations of the radiation of carbon. The flame was controlled by measurements of the pressure of the gas.

The proposition of Féry looked to the use of a long, slender flame. He used a bit of thermometer tubing of internal diameter of 0.5 mm. as a jet. With this he found that the luminous intensity of the flame was proportional to the flame height between the limits of 1 cm. and 2.5 cm.; that is, he substituted for control by pressure measurements. control by measurement of the flame height.

What is now known of the properties of the acetylene flame indicates that a search for the best method of producing and defining an invariable acetylene flame would be fruitful of valuable results.

It has been proposed to employ as a standard flame one in which a pure gas burns under standard conditions in a pure atmosphere, both of known chemical composition. A practical method of burning pure acetylene in an atmosphere of pure oxygen has been found, as well as direct and interchecking methods for the control of such a flame, but the investigation has not led to any definitive result.

Until a more satisfactory standard is introduced, photometrists are practically limited to the choice of either a pentane standard or the Hefner lamp as primary standards. An incandescent lamp carefully seasoned and measured furnishes for most purposes a thoroughly satisfactory secondary standard, and we are looking forward to the time when the National Standardizing Bureau will establish an authoritative standard and will measure and will certify to lamps sent to them for this purpose.

1. *Comptes Rendus*, Vol. 122, p. 79, 1896.
2. TRANS., A.I.E.E., Vol. XII., p. 500., 1895.
3. *Comptes Rendus*. Vol. 126, p. 1192, 1898.
4. *Physical Review*, Aug. and Oct., 1901.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3rd, 1902.

ELECTRIC GAS LAMPS AND GAS ELECTRICAL RESISTANCE PHENOMENA.

BY PETER COOPER HEWITT.

On a former occasion I had the honor of showing to the members of the INSTITUTE lamps utilizing the conductivity of gas for illuminating purposes, including experiments illustrating certain laws of conductivity of gases, and I also presented curves directing attention to various characteristics. It gives me pleasure to-night, while showing lamps in operation lighting this room, to describe some of the phenomena exhibited by the lamp and to indicate some of the difficulties encountered in determining the relative values of the resistances therein.

The mercury gas lamps exhibited to-night are operated on the standard Edison 118-volt direct-current circuit installed in this building; lamps of this class consume amounts of current varying from 1 to 6 amperes, and the efficiency is approximately ½ watt per spherical candle power. Under better conditions as high an efficiency as ¼ watt per spherical candle power has been obtained, determined by careful and accurate measurements. Measurements were made by measuring sections of the lamp varying in length from ¼ of an inch to 3 inches, shielding the lamp and leaving a slot in the shield of the length mentioned, and measuring the light transmitted through the slot. These measurements have been made with lamps of various diameters. Dr. Max von Recklinghausen has made independent measurements, comparing the illuminating value of the lamps with incandescent lamps of equivalent rated candle power, and the results of such tests agreed remarkably well with the measurements obtained upon photometers.

I have made lamps with diameter of bore less than ⅛ of an inch and as large as 3 inches, and from less than 3 inches in length up to over 10 feet, giving from less than 10 candles up to fully 3,000. Lamps of very small bores give more trouble in manufacture and operation than those of moderate size. Lamps of innumerable shapes and dimensions have been constructed and great variation of candle power for various diameters obtained. There appears no reason why lamps may not be made of any size required and of any desired candle power per inch within wide limits, the only limitation appearing being that imposed by softening of the glass when too many candle power per inch are produced. The general rules established regarding their operation hold good in so far as examined, and it is possible to predetermine with almost absolute exactness the voltage, current consumption and candle power of a lamp when the manufacture is perfect.

The light produced by pure mercury gas comprises orange-yellow, lemon-yellow, green, blue, blue-violet and violet; and although all shades of these colors may not be present, their absence would not be so seriously felt were it not for the absence of the red. For some purposes the lack of red in the spectrum is objectionable, but for many uses it is a positive advantage.

For shop work, draughting, reading and other work where the eye is called upon for continued strain, the absence of red is an advantage, for I have found light without the red is much less tiring to the eye than with it. It is possible to transform some waves of this light, especially the yellow light, into red light, and thus in a measure to overcome this defect where required for general indoor illumination. A moderate amount of ordinary incandescent light interspersed with the mercury gas electric light serves to supply the deficiency, and the mixture may be made most satisfactory. For ordinary street lighting purposes the mercury light is available even without the red, and it should be noticed that this light has very great penetrating power and seems to be effective through greater distances than an equivalent amount of measured candle power from the ordinary incandescent lamp. This may be due to the fact that the waves of the red light are less penetrating than those waves which are present in the mercury light, and hence the least valuable portion of the spectrum having such illuminating effects is omitted, and the energy is practically expended in the more useful portions of the spectrum.

I have made lamps in which this color objection has been overcome, sacrificing on some occasions the extremely high light efficiency obtained in this particular lamp. Without doubt lamps of this type will be produced whose light will be even more beautiful than this light is objectionable; in fact, I have produced very beautiful and becoming light. Every gas gives its own particular spectrum when traversed by current, only part of which is visible, and that one having its spectrum richest in the visible portion is the most efficient for service as a lamp. Each develops its own color peculiarities and presents its particular electrode phenomena, chemical and physical, but I am convinced it is only a matter of patient work to render many gases practically available as light-giving media. When it is considered that this light, when obtained with mercury gas, has an efficiency at least eight times as great as that obtained by the ordinary incandescent lamp, it will be appreciated that it has its use in places where lack of the red is not important, for the economy of operation will much more than compensate for the somewhat unnatural color given to illuminated objects.

I would like to state some of the phenomena that had to be unravelled before it was possible to establish the laws governing the operation of electric gas lamps. The conductivity of the gas of the lamp, which is the most important factor, is dependent upon the diameter of the gas column, the length of the gas column, the density of the gas in the column and the resistance factor of the particular gas; with these must be considered the resistance at and about the respective electrodes to obtain the total resistance presented by the lamp. In determining the relative values of these it was assumed that the resistance of the gas column would vary directly as the length; this has so far proved to be true. From the results of a great number of experiments, and from some particular ones, I was able to demonstrate that the resistance varied inversely with the diameter; not as a square, as in metallic conductors, but very nearly as the first power. It is very difficult to obtain identical surroundings for lamps of different diameters, and I am of the opinion that any discrepancy that occurs is due to difference of environment. I was able to demonstrate that the resistance varies inversely with the quantity of the current passed, which means that the lamp requires a constant voltage unless some change takes place. The voltage across the terminals of the lamp is modified by the density of the gas, a gas having a density of maximum conducitivity or a certain definite amount of matter and molecular movement best suited for conduction. Beyond the point of maximum conductivity the resistance appears to increase absolutely directly with the density, but I wish to state that my means of measuring at these low densities were not sufficiently accurate. The density is an entirely controllable factor, and is one of the best means of controlling the voltage. The laws above stated appear to hold good as to gases, generally.

The electrode resistance at the positive, providing there is no alteration of the chemical or physical condition of the electrodes, may, from a practical standpoint, be regarded as being very slight and will be neglected for the present.

The negative electrode resistance offered very great difficulties and required long and patient experimental investigation. I found that it consisted of a variety of factors, and I will briefly direct attention to those which appear to have the more important bearing upon the operation of the lamp. There is a reluctance to the initial passage of current which appears as if self-created by the current—as if by induction. Upon increasing the voltage applied thereto, current passes to a very small extent and thereupon there is a fall in resistance. To increase this small amount of current the voltage must be still further increased. On further increase of current this resistance apparently ceases and there is an enormous decrease of voltage. This resistance apparently does not exist when chemical or physical alteration occurs at the electrodes.

When the last named resistance is overcome by reason of passing current, a flame may be noticed proceeding from the negative electrode in a direction perpendicular to the surface from which it issues. If this flame meets the current in a right line, that is to say, projects in the direction of the flow of the current at the point of meeting, the total resistance of the lamp is materially greater than when the flame proceeds in a direction at an angle to the flow of the current.

When the flame is proceeding from the negative electrode at an angle to the line of the current, then the resistance at the negative electrode, under the conditions which are established is reduced, and practically speaking, the principal and controlling resistance of the lamp is then located in the gas-path proper.

The reluctance to starting is greatly modified by charging the surface of the lamp exterior to the negative electrode positively, and also in a less degree by dissipating the charge that collects there. It is for this reason that the lamps have a conducting band exterior to the negative. This resistance may also be modified by charging and discharging the lamp with a high voltage current.

I may here add that these initial resistances to the passage of current may be overcome by an impulse of high potential, as by the discharge of a reactive coil.

Electrical relations, as well as chemical, exist between the various kinds of gases used and electrodes of different materials, so that the presence of some other matter, " foreign matter," may bring about a total change of conditions and phenomena which normally should exist at the negative electrode in a state of purity. These conditions give rise to new and unexpected phenomena, and phenomena of great importance are brought into existence at the positive electrode. In the practical manufacture of the lamp, when abnormal conditions arise, that is to say, when other phenomena than those above outlined appear, or those above outlined do not appear, it is customary to attribute them to the presence of " foreign matter."

From what has been stated, it will be seen that the problems, which had to be solved to produce a lamp, comprised, among others, not only the determination of the conductivity of the gas column, involving the relations of the length and diameter, but determining the relative values of the other different factors of the electrical resistances, resistance at the electrode, etc.; determining the conditions accompanying varying densities, the variations in the conductivity with respect to the amount of current flowing; also methods of finding a pure gas with stable chemical and physical conditions within the lamps, and also determining the relations of the electrodes and gas with respect to each other under operating conditions.

In one experiment shown upon the former occasion referred to, the initial resistance to the passage of the current was illustrated and the electrical leak through this resistance was measured; but at that time no attempt was made to point out the several resistances or factors thereof which have been referred to above.

In some particular forms of lamp the resistance at the negative electrodes has been availed of to render the negative electrode itself a source of light. Such conditions were established that no physical or chemical change took place at the negative electrode, and it developed that the electrode should then be heated to any desired temperature. Iron electrodes under these suited for conduction. Beyond the point of maximum conductivity the resistance appears to increase absolutely directly with the density, but I wish to state that my means of measuring at these low densities were not sufficiently accurate. The density is an entirely controllable factor, and is one of the best means of controlling the voltage. The laws above stated appear to hold good as to gases, generally.

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I might mention an interesting negative electrode experiment where an ordinary lamp about 30 inches in length contained a rod of metal one-eighth inch in diameter, projecting from the mercury negative to an eighth of an inch of the positive electrode, which was located as usual, and a movable bridging piece permitted bringing this rod into electrical connection with the positive. On forming contact and breaking, the current shoots to the mercury negative, although the total resistance over the lamp requires 60 volts with about two amperes passing, while that of the rod was negligible with respect to ohms.

The presence of slight impurities in the lamp serves to vary the resistance to starting in a very marked degree. Under some conditions impurities or " foreign matter " facilitate conduction, whereas under other conditions " foreign matter " serves to greatly increase the resistance.

Referring again to the flame occurring at the negative which is present while the lamp is in operation, it may be stated that the direction of the flame is largely, if not entirely, independent of the direction of the current, and is determined by the plane of the surface receiving the current. The direction of the flow of the current to that surface is, generally speaking, through the shortest path from the positive electrode, so that if the entrance plane of the negative electrode surface be out of the perpendicular to the flow of the current, then the flame may be made to proceed in a direction out of the path of the current and thus will not interpose its resistance to the current flow. In some of the types of lamps shown here to-night, the surface of the mercury constituting the negative electrode, as will be seen, does occupy such a position with relation to the path of the current, and the flame proceeds in a line out of the path of the current. In some of the lamps, for the purpose of causing the position at which the current passes into the negative electrode, to remain fixed and the flame regulated, the metal leading-in-wire is carried to a point at the surface of the mercury, and the path of the current once being fixed upon this point, remains there instead of wandering about the surface of the mercury, the current entering the meniscus. The flame may be deflected and its position controlled by the use of a magnet when so desired. Where no point is used, there is a tendency for the current to wander and burrow, as it were, into the body of mercury. This results in temporary depressions, so that the flame may proceed from the walls of these depressions in a direction at an angle to the direction taken by the current, but the wandering of the current about the surface of the mercury will necessarily cause a constant shifting of the direction of the flame and cause variation in the resistance of the lamp.

I have used other gases than the vapor of mercury as the gas path, but mercury is more convenient for general experimental investigation for many reasons, among them the fact that as a negative electrode, its resistance is stable, the readiness with which the alteration of its condition may be brought about, the high efficiency of a mercury gas as a light giving medium, and also the fact that it can easily be obtained in a fairly pure state.

NOTE.—For previous experiments referred to above, see *Electrical World and Electrical Engineer*, April 27, 1901; *Scientific American*.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902.

EDISON'S TUNGSTATE OF CALCIUM LAMP.—THE NERNST LAMP.—RADIUM, POLONIUM AND ACTINIUM.

BY WM. J. HAMMER.

EDISON'S TUNGSTATE OF CALCIUM LAMP.

Through the courtesy of Mr. Edison, I am enabled to present to the INSTITUTE this evening several samples of what has been termed " Edison's X-ray lamp," of which brief descriptions have been given in the press on several occasions. But this occasion is, I believe, the first time that the lamp has been publicly exhibited. It is well-known that in connection with Mr. Edison's experiments with Roentgen rays, and in the construction of his fluoroscope, he experimented with thousands of chemical substances, and the substance which he found most suitable for use on the fluorescent screen was tungstate of calcium, which, together with barium platinum cyanide, constitute the substances most extensively employed in fluorescent screens.

Mr. Edison has also made a large number of experiments in which he has fused certain fluorescent substances on the internal walls of X-ray tubes, which substances upon being excited by X-rays have caused the tube to glow with great brilliancy.

These lamps are coated internally with tungstate of calcium; the crystals of which have been fused by the X-rays, the tube being slowly rotated while the substance is being acted upon. The apparatus which is before you is the same apparatus which I used last evening in operating these tubes most successfully at my house; and Mr. Edison also showed me these tubes operating at his laboratory most successfully the day before yesterday.

I regret to state that while making some experiments with my large coil early this evening, the secondary winding was broken down, and I will not be able to show you the lamps burning under the best conditions, at which time they present a very brilliant and beautiful light, although at present it is not possible to operate them continuously for any great length of time.

Through the courtesy of Mr. Hewitt, who has kindly lent me his small coil, I will be enabled to operate one of the tubes which I have, and which will serve to indicate to some extent the results of Mr. Edison's experiments in this direction. The other three tubes which I have are of too high a vacuum to operate successfully on this small coil.

NERNST LAMP.

I had hoped to have the pleasure of showing you this evening one or more samples of the osmium lamp, and to tell you some things of interest connected therewith; but it seems that the time is hardly ripe for the presentation of this matter before the INSTITUTE, though I hope to do so in the near future.

I am enabled, however, to present for your consideration to-night various types of American, English, German and Hungarian Nernst lamps, of both self-lighting and torch-lighting types. Some of the foreign types of lamps I had the pleasure of describing in detail in my paper at the 151st general meeting of the INSTITUTE on Feb. 18, 1901; and the Westinghouse type of Nernst lamp has been very ably presented to your notice by Mr. Alexander J. Wurts at the summer meeting of the INSTITUTE at the Pan-American Exposition at Buffalo.

Therefore, in view of the extent of our program this evening, I will not go into details regarding these lamps, which may be examined at the close of the meeting, but would call your attention in passing to the German Nernst lamps which are shown burning here this evening, and which are the latest types manufactured by the Allgemeine Electricitäts Gesellschaft of Berlin, and which have very recently arrived on this side of the water. The large lamp containing the pendant conical heating coil is of a new type, which is here publicly presented for the first time. I would refer those particularly interested in this subject to papers already referred to, which have been presented to the INSTITUTE.

RADIUM, POLONIUM AND ACTINIUM.

Since the discovery a few years ago by M. Henri Becquerel of the remarkable uranium radiations, which have since been known by his name, such an amount of attention has been given by physicists to the study of radiant matter, and to speculative theories as to the constitution of matter, that it will probably be some time before our views can settle down and adjust themselves to the new phenomena which have been presented and are daily being brought to our notice.

Becquerel demonstrated that compounds of uranium, and especially the metal itself, prepared in the electric furnace, possessed very great radio-activity. Thorium compounds, especially thorium oxide, are next in activity, though far weaker.

Mme. Sklodowska Curie and M. Pierre Curie noted that other elements were inferior to these, and that the compounds were inferior to the metals themselves. Bohemian pitch-blende and two other compounds of uranium suggested to them by their greater radio-activity to that of pure uranium, that some new substance existed more active than uranium, and after most exhausting and painstaking investigations, they discovered a metal identical with bismuth in its chemical characteristics, and far more radio-active, which they named "polonium" after Poland, Mme. Curie's fatherland. A further search resulted in the discovery of another new metal very similar to barium in its chemical properties, which they called "radium," which was even far more radio-active. This was followed by the discovery by M. A. Debierne of a third element, which he has named "actinium," which has chemical characteristics similar to thorium. It has as yet not been fully demonstrated that these three are actually new elements, as none has as yet been secured in a pure state. (See note 1 of appendix.)

It is not my purpose to-night to go fully into the investigations which have been made in these remarkable substances, with which many of you are doubtless familiar; but in view of the interest which radium has excited in the scientific world, and as there are probably few in this audience to-night who have had an opportunity of seeing this remarkable, and up to the present time, exceedingly rare substance, I take pleasure in presenting a small quantity for your consideration, which I have secured through the courtesy of Prof. Dayton C. Miller, who imported the same from Paris. The tiny sealed glass tube, which I hold in my hand, contains about one gramme of radium, which cost in Paris about ten dollars.

I have prepared a few notes regarding certain properties of radium, which I will read, and which I trust will prove of interest,[1] after which, if the lights are put out, I will pass around

[1] Prepared from data given to the writer by Prof. Curie, also data from compilations of E. E. Fournier D'Alba in *London Electrician*, *Science Abstracts* and other sources, these being abstracts of *Proceedings of Royal Soc.—Phil. Soc.—Phys. Zeitschrift—Ann. der Physik—Deutsche Phys. Ges. Verk.—Chem. News—Comptes Rendus—Soc. Francaise Phys. Bull.—Jour. de Physique*, etc.; see also, Prince Kropotkin on "Unsuspected Radiations" in *The Nineteenth Century*, December, 1900.

the room, and you can observe not only the illumination produced by the radium itself, but also the radio-activity of the cotton, which I will wrap around the tube.

An extensive dealer in chemicals informed me recently that the treatment of 5,000 tons of uranium residues would probably not result in the production of a kilo of radium. The present market price in this country is $4.50 per gramme, or approximately $2,000 a pound.

M. and Mme. Curie and Mr. H. Giesel have succeeded in further purifying radium, and I understand that a preparation will shortly be on the market here at the cost of $35 per gramme. The chloride and bromide of radium are the most brightly luminous compounds, but all the salts are more or less radio-active.

The radium preparation which I am able to show you to-night differs from such substances as sulphate of lime and various compounds of barium, calcium, strontium uranium, etc., which possess the property of glowing in the dark when exposed for some time to light, or are rendered active by electrical or heat vibrations, in that radium requires no such exposure to become incandescent, but will glow for months and even years, and also has the property of causing other substances near it to become radio-active, and to retain this activity in many cases for a long period. Radium has been called a constant source of " X " or Roentgen rays and cathode rays.

H. Becquerel estimates that the energy expended by radium is a few C. G. S. units per second, and a few ten millionths of a volt, and that at this rate the loss of matter would be about one milligramme in a thousand years. He also finds that the radio-activity of radium is 900 times that of metallic uranium, while that of polonium is only 400 times. (See note 2 of appendix).

He also calls attention to the facts demonstrated by M. and Mme. Curie and himself, that radium radiations carry negative charges like cathode rays, and like cathode rays also can discharge electrified bodies at a distance as well as render the air gap between the plates of a condenser, conducting; and the current passing, susceptible of measurement by an electrometer. Also that many bodies when exposed to radium influences acquire temporarily the power of rendering the air conducting, and of discharging electrified bodies, all of which afford proofs of the contention that there is in reality a continuous emission of energy by transport of matter from radio-active bodies; and

H. Becquerel estimates the speed with which these particles are radiated at half to two-thirds the speed of light.

These investigations have also shown that radium radiations are of three kinds, a portion deviable by a magnetic field, a portion non-deviable and readily absorbed, and a third weaker portion of diffused, non-deviable rays attributable partly to secondary rays.

M. and Mme. Curie state that the deviable rays have the greater penetrative effect, but constitute but a small portion, and that the non-deviable rays, which constitute the major portion, do not travel further in the air than 7 cm. from the source. According to M. Becquerel, there seems to be no difference in the deviable qualities of radium rays in the air or in a vacuum. M. and Mme. Curie show that polonium only emits non-deviable rays, and that these only travel 4 cm. from the source in air.

Giesel's polonium, on the contrary, emits both deviable and non-deviable rays; and J. Elster states that magnetic deviation of polonium rays is produced in a vacuum, and seems to exceed deviation of radium rays under same conditions.

S. Meyer and E. R. Von Schweidler, in studying the absorption of radium rays call attention by plotted curves to the fact that the first few hundredths of a millimetre are most effective in the absorption, and that it may be concluded that with radium rays, as in the case of Roentgen, uranium and thorium rays, the radiations consist of a large number of rays of different nature.

According to M. and Mme. Curie, radium rays act in many ways like light. They reduce silver salts, peroxide of iron and bichromate of potash in presence of organic substances; but they also color glass, porcelain and white paper, and they transform greenish yellow platino-cyanide of barium into a brown variety.

Giesel had prepared platino-cyanide of barium with a trace of radium. This spontaneously became brown, and it then polarized light like tourmaline. He also found that this colored rock salt just as cathode rays do, or the vapors of alkaline metals, and furthermore showed that radium salts, brought near the temples or to the closed eyes, produced a sensation of light.

M. Becquerel, referring to the chemical action of radium rays, says that radium and uranium rays act upon silver gelatino-bromide, but produce no effect upon Daguerre plates, or upon photographic papers, and says that colorations of glass, porcelain, paper and certain crystals, as well as the painful physiological effects, also belong to this class of phenomena. He also calls attention to the transformation of white into red phosphorus in 24 hours, the reduction of mercuric chloride in the presence of oxalic acid with the precipitation of calomel, and finally the destruction of the germinating power of seeds after long exposure.

Becquerel also shows that radium rays possess the same power as the electric spark, or the prolonged action of violet or ultra-violet rays, of restoring the phosphorescent properties under exposure to heat of a body deprived of them by over-heating.

O. Behrendsen found that by cooling radium in liquid air its radio-activity was reduced more than one-half. On heating again to a normal temperature, a slight increase of radio-activity was discovered, thus agreeing with the behavior of phosphorescent bodies described by Lumiere. (See note 3 of appendix.)

Curie and Debierne state that while all bodies become radio-active when placed in a closed vessel with solid salt of radio-active barium, this effect may be increased 40 times and made more regular by using the aqueous solution instead of the solid salt.

M. A. de Hemptemne, who discovered that gas which becomes luminous at a certain pressure under the influence of electrical vibrations becomes luminous at a higher pressure when exposed at the same time to "X" rays, also found that air which became luminous only at an exhaustion as low as 33 mm, became luminous at a pressure of 44 mm, brought into proximity with a radio-active substance, and at the same time the color of the light changed from reddish violet to yellowish green.

Dr. C. Runge, the great German specialist, found that radium gave three distinct lines belonging to no other element. Demarcay had previously given these lines, together with some twelve others which he claimed to belong to raduim, but thus far had not been proved to belong to radium. (See note 4 of appendix).

Radium rays, like Roentgen or "X" rays, produce serious physiological effects. This was first demonstrated by Messrs. Walkoff and Giesel, the latter having kept on his hands for two hours a celluloid capsule containing radiferous barium bromide. The rays acting through the celluloid caused a slight redness of the skin, and two or three weeks later inflammation set in, and the skin finally sloughed off.

M. Curie repeated Giesel's experiment upon himself, using radiferous barium chloride, acting through a thin sheath of gutta percha, upon his hand. The activity of the substance was comparatively feeble, being about 5,000 times that of metallic uranium. The rays left a red spot on the hand six centimetres square, which appeared like a burn, but gave no pain. In a few days the redness increased, and on the twentieth day crusts formed, ending with a sore which needed dressing. On the forty-second day the epidermis commenced to form on the edge, and fifty-two days after the action one square centimetre remained sore and of a greyish color.

M. Becquerel, on carrying a small sealed tube containing a few decigrammes of very active radiferous barium chloride, the activity of which is 800,000 times that of uranium, underwent an experience of the same kind. The matter enclosed in the glass tube occupied a cylindrical volume of from 10 to 15 millimetres by 3 millimetres in diameter; the tube wrapped in paper, was kept in a small paste-board box. On April 3 and 4, this box was placed several times in a corner of a vest pocket for a period, the total duration of which amounted to six hours. On April 13 it was perceived that the radiation through the tube, the box and the clothes had produced a red spot on the skin, which became deeper as the time passed, marking in red the oblong form of the tube, and assuming an oval form 6 centimetres long by 4 centimetres wide. On April 24 the skin fell off; then the part most affected sank in, beginning to suppurate; oleo-calcareous dressings were applied to the sore for a month, the diseased tissues were removed, and on May 22, that is to say, forty-nine days after the action of the rays, the ulcer closed, leaving a scar which marked the place of the tube.

"While care was being given to this burn," he says, "there appeared about May 15 a second oblong red spot opposite the other corner of the vest pocket in which the active matter had been placed. The exposure had been of short duration, an hour at most. Erythema now appeared, thirty-four days at least after the exciting action; inflammation developed, presenting the appearance of a superficial burn; on May 26 the skin began to fall off; on receiving the same care as the first, this burn appeared to be more rapidly cured.

"In the interval of these observations, on April 10, 11 and 12, the same tube of active matter, enclosed in a lead tube whose walls were about 5 millimetres thick, was kept for forty, hours in another vest pocket, but has so far been attended with no physiological effect."

"It may be added that Mme. Curie, by carrying in a small sealed tube, a few centigrammes of the same very active matter which had caused the effects described above, had similar burns, although the small tube was enclosed in a thin metallic box. In particular, an exposure of less than half an hour produced at the end of fifteen days a red spot, resulting in a blister similar to a superficial scald. Fifteen days were required for the cure. These facts prove that the duration of the effects varies with the intensity of the active rays, and with the duration of the exciting action."

" Our hands have been also affected. There has been a general tendency to desquamation, the extremities of the fingers which have held the tubes or capsules containing active products become hard and very painful. In the case of one of us, the inflammation of the extremities of the fingers lasted about fifteen days, and indeed after the falling off of the skin, the painful sensations have not yet completely passed away at the end of two months."

As illustrating the action of radium rays upon bacteria, E. Aschkinass and W. Caspari speak of exposing cultures of *micrococcus prodigiosus* to a radium preparation, and state that the rays killed the germs very effectively in about three hours.

APPENDIX.

Since presenting the above paper on radium, I have visited Paris and had the pleasure of spending some time at Professor Curie's laboratory at the Ecole de Physique et de Chimie Industrielles, and Professor Curie has shown me some very interesting experiments and apparatus. I asked him to criticise the matter which I had prepared, and he very kindly gave me in writing the following notes which are numbered 1, 2, 3 and 4, and refer to the paragraphs in my notes which are similarly numbered.

NOTES BY PROFESSOR CURIE.

" 1. It is well known to-day that radium is a new element characterized by a special spectrum. Radium has an atomic weight equal to 225. (Refer to the report given in the *Comptes Rendus* of July, 1902).

2. Radium, actinium and polonium possess an activity which is a million times that of uranium.

3. I found, on the contrary, that radium emits exactly the same quantity of Becquerel rays when it is in the liquid air, as it does at the normal temperature of the atmosphere. The luminosity of the chloride of radium is stronger in the liquid air than in the atmosphere at a normal temperature.

4. The spectrum of radium has been fully studied by Demarcav and the rays that he points out certainly belong to him."

I asked Prof. Curie whether there existed at the present time, or whether there has ever been made, a kilo of radium, and was informed that during the past three years only between five hundred and six hundred grammes of radium had been manufactured, and that this included all grades of purity, and he also stated that radium, as a metal, did not exist, practically all which had been produced thus far being chloride of radium associated with barium; but he showed me a tiny tube of chemically pure chloride of radium, which he said was the only sample of it in a pure state that existed in the whole world. It was about the size of a buck shot and contained less than three one-hundredths of a gramme, and on my enquiring its value I was told that it had any value that one wished to give it; but that twenty thousand dollars could not buy it. It was with this sample of pure chloride of radium that M. Demarcay made his tests with the spectroscope. demonstrating that radium was a new element, for it showed no lines other than those characteristic of radium.

With this sample the atomic weight of radium was also determined to be 225, being considerably higher than that of barium, which is 157.

I saw at the laboratory of the Societé Centrale de Produits Chimiques, where the radium is manufactured, a similar tube of radium of a lower grade, there being still a considerable trace of barium in it, which tube had a value of $5,000. Prof. Curie told me that he would not care to trust himself in a room with a kilo. of pure radium, as it would doubtless destroy his eyesight and burn all of the skin off of his body, and probably kill him. He showed me the scars on his arm, one of which looked as if he had had a very serious ulcer due to a radium burn, which, I understand, had taken fifty-two days to heal: and the other showed that the skin had been blistered and slightly scarred, the latter was caused by an exposure of but five minutes to some radium of very high activity, the more serious scar was due to an exposure of one hour and a half to some radium of much lower radio-activity, approximately 5,000. All of the radium manufactured in France, is made under the supervision of Prof. Curie, and is tested and the samples classified by him. He informed me that whereas the best German product shows an activity of only 300 times the activity of uranium, the best commercial product, which is at present on the market in France, has 7,000 times the activity of uranium, and this at present costs $100 a gramme in Paris. Through the courtesy of Prof. Curie I was enabled to secure from the manufacturing laboratory a number of tubes of radium of varying degrees of radio-activity, and sample tubes of polonium of both bismuth-polonium metal and nitrate of bismuth and polonium, each possessing a radio-activity 300 times that of uranium, and tubes of pitch blende, uranium, uranium residues from which the radium is extracted, etc., I have also secured through the courtesy of M. P. Boulay of the Societé Centrale an interesting set of photographs made by radium rays. I shall be glad to show these to any members of the INSTITUTE interested in this subject.

Discussion.

President Steinmetz:—Gentlemen, the topic of to-night's discussion is "Light and Methods of Illumination." The problem of producing light consists of transforming some form of energy into radiation within that range of wave length which exerts the physiological effect of visibility. Light, therefore, is a physiological and not a physical quantity, and therein lie most of the difficulties in comparing and measuring light and reducing the unit of light to mechanical units.

Until the latter part of the last century all the methods of producing artificial light had been based on combustion; that is, transformation of chemical energy into light. With the advance of electrical engineering the transformation of electrical energy into light has been introduced. Neither of these transformations, however, is direct, but from heat as an intermediary form of energy, and therefore, owing to the inherent character of heat as low grade energy or irregular motion, the efficiency of such transformation must be very low. An essential increase in the efficiency of light production can, therefore, be found only by devising some direct transformation of electrical energy into light energy, without the intermediary of heat.

The means for producing light used heretofore, or proposed, are incandescence, heat luminescence and electro-luminescence.

If heat energy is communicated to a solid body, with increase of temperature the body sends out radiations, the intensity of those radiations increasing with the temperature and the average wave lengths decreasing with the increase of temperature. When a certain temperature is reached, radiations begin to appear within the visible range and the body becomes incandescent. With increasing temperature, the average or mean wave length decreases, and the percentage of visible radiation, therefore, increases; that is, the efficiency of light production increases. This efficiency, however, is limited by the limit of temperature feasible. This limiting temperature is the boiling temperature of the most refractory body, which appears to be carbon.

In the production of light, we have to distinguish between total efficiency, as ratio of energy output in the form of radiation within the range of visibility to total energy input, and radiation efficiency, as ratio of the energy of visible radiation to total radiation. These two efficiencies differ by the energy lost by heat conduction, convection by air currents, etc. In the incandescent lamp this loss of energy is small, and the total efficiency practically equal to the radiation efficiency, but the radiation efficiency is lower, due to the necessity of keeping the filament temperature sufficiently below the boiling point of carbon to secure the desired length of life. In the arc lamp, owing to the crater being at the temperature of the boiling point of carbon, the radiation efficiency is the highest which can be reached, but is still very low, and the total efficiency differs considerably from the radiation efficiency, especially with smaller units of light. An increase of the radiation efficiency could be secured only if a body more refractory than carbon could be found, and this is not probable. Osmium, if at all more refractory than carbon, which is questionable, does not differ sufficiently to effect a considerable increase of radiation efficiency, and is, besides, excluded from extended use by its very limited existence. Carbides, as far as known, melt in the electric arc, hence are less refractory than carbon. It thus follows that with the carbon arc and incandescent lamp, the limits of efficiency of light production by incandescence have been approached so nearly that an essential increase cannot be expected.

Some solid substances, mainly metallic oxides, however, have an abnormal radiation at some intermediate but fairly high temperature. That is, the percentage of visible radiation emitted by these bodies, and thereby their radiation efficiency is greater than corresponds to the temperature, and therefore as transformers of heat energy into light they are more efficient. This phenomenon may properly be called *heat luminescence* and has been utilized successfully in the incandescent gas light, the Welsbach burner, and is being introduced in the pyro-electrolytic lamp, commonly called the Nernst lamp.

It is very questionable, however, whether thereby an essential increase of efficiency can be secured in electric lighting, since the gain due to the abnormal radiation efficiency is more or less lost by the necessity of operating at a temperature below the fusion point of the pyro-electrolyte, thus considerably below the temperature of the carbon arc.

The different methods of more or less direct transformation of electrical energy into radiation may be combined under the name "Electro-luminescence." Under electrical excitation, non-conducting gases in a vacuum, under high electric stress but with small volume of current, are set in faintly luminous vibration and so give light in the Geissler tube. Metallic vapors at moderate electric pressures, when passing considerable volumes of current become luminous, whether in a vacuum or at atmospheric pressure in air or in an enclosed space, and give a luminous arc. Solid substances in a very high vacuum, under electro-static bombardment send out light.

The Geissler tube as a source of light has the objection of very low intrinsic brilliancy, and probably also very low efficiency, if not very high and commercially impracticable frequencies are employed. Molecular bombardment has the objection of requiring excessive voltages, and especially of exerting a mechanically destructive effect upon the enclosing vessel. A prospect of improvement of the efficiency of electric lighting thus appears only in the direction of the luminous arc, either in vacuo or at atmospheric pressure. The light of the luminous arc and also the Geissler tube is monochromatic, that is, the radiation does not follow the temperature law, but the radiation efficiency is practically independent of the temperature, and the radiation takes place only at some definite wave length, corresponding to the spectrum lines. The radiation efficiency then is the ratio of the energy of the spectrum lines in the visible range to that of all the spectrum lines, and if most of the intense spectrum lines of a substance lie in the visible range, this substance will give a very high radiation efficiency, independent of the temperature. In addition thereto, however, the spectrum lines should be distributed over the whole range of the visible spectrum, so as to give a fair color to the light.

So far, no electric lamp utilizing a luminous arc has been sufficiently developed to be in commercial use, and the difficulties encountered in this problem are very great.

Now, after this introduction I give the floor to Dr. Louis Bell, for his paper on "Methods of Illumination." I may state that I have been instructed by the Committee on Papers that owing to the number of papers and the discussion which we expect, the time given to each reader of a paper must be strictly limited, and ten minutes will be given for the author of each paper to abstract his paper, and twenty minutes to Dr. Bell, as the reader of the fundamental paper.

Dr. Bell gave an abstract of his paper. [See page 5]

PRESIDENT STEINMETZ:—Gentlemen, according to our present custom we will postpone the discussion of Dr. Bell's paper until after the reading of the other papers. I will call now upon Mr. W. D'A. Ryan for his paper on "Illumination and Units of Light," as dealing with a problem similar in its characteristics to some parts of Dr. Bell's paper.

Mr. Ryan presented his paper. [See page 29]

PRESIDENT STEINMETZ:—Gentlemen, you have listened to a very interesting paper, in which Mr. Ryan has brought out very forcibly that it is not the total volume of light, but its distribution, which is of practical importance in the problem of illumination. The next paper by Mr. S. Everett Doane deals with the same problem, although he arrives at a very different conclusion. I therefore call upon Mr. Doane to give his side of the question.

Mr. Doane presented his paper. [See page 43]

PRESIDENT STEINMETZ:—Gentlemen, I can concur in some statements of the last speaker. I had the same experience—not from an automobile, but from a bicycle last summer—that the only way to find the road in a suburban district where it was illuminated by arc lamps was to watch the reflection from the railroad track. Regarding the advantage of distributing by incandescent lamps, I had some experience, also. I tried to light my greenhouse, about a thousand square feet in area, by twenty-five incandescent lamps, well distributed. The meter was recording power, but I could not read by the light. I had to supplement it by putting in another horse power in one large unit of arc lamp, which gave satisfaction. In this case, there was no reflected light, the walls being all glass. Knowing the undesirability of one large unit of light and the harsh shadows it casts, I still put one arc lamp in one large room in my laboratory, and got a strong, well-distributed illumination. But here the walls were painted brilliantly white. That leads me to the point I desired to bring out, since it is not very thoroughly brought out in the papers, the effect of the surroundings on the distribution of illumination. In a city street with houses on both sides, reflecting a very large amount of light, probably more than the direct light, very few large units may give fairly satisfactory illumination. But on a suburban road with no houses, large units of light mean more or less illuminating the universe, and not the road which we want illuminated. We have drifted in these papers toward the arc lamp, and I now call on Mr. Howell to read his paper on "The Incandescent Lamp of To-day." [See page 47]

Mr. John W. Howell read his paper, supplementing it by the following remarks:

"Mr. Steinmetz has spoken of the selective radiation of certain of the rare earth oxides in reference to the efficiency of lights, and has quoted the Welsbach mantle and the Nernst lamp as illustrations of the use of materials which give more light at a given temperature than carbon for example. The Nernst lamp interested me very greatly when it appeared. I wanted to see whether the Nernst lamp had a selective radiation and would give a larger amount of light at a given temperature than we would expect from analogy with the carbon filament, and I find that it does not. The filament of a Nernst lamp has only 6/10 the amount of surface that carbon has at the same efficiency in watts per candle, which is a rather surprising result. It indicates that the lamp is operated at a very high temperature and gets the color of its light, which is its most valuable characteristic from the very high temperature at which it is operated, and not, I believe, from any selective radiation or from any more radiation at a given temperature than we would expect if it were carbon.

President Steinmetz:—Gentlemen, as very well brought out in Mr. Howell's paper, it is the extreme simplicity of the incandescent lamp which is its most satisfactory feature, and which gives it a superiority over all these new illuminants, no matter how high their efficiency. The great value of simplicity you can best realize when watching the actual use of the incandescent lamps in those places where no special effort is made to replace them. You will find the average use of the lamp is far longer than permissible, and lamps are practically never replaced except when burnt out. That is, the average customer rather than replace the lamp, pays twice as much for the light. I now call upon Dr. C. H. Sharp to abstract his two papers dealing with the question of "Standard of Light" and "An Acetylene-in-Oxygen Flame" as proposed as a means of giving a primary standard of light.

Dr. Sharp gave an abstract of his papers. [See pages 51 and 55]

PRESIDENT STEINMETZ:—The next paper on the program deals with a light of the future, a light differing from the incandescent lamp as much in efficiency as it differs in color. It is a real arc light; that is, a lamp in which the light is given by the electric arc, while that which we have heretofore called an electric arc lamp is not so much an arc, as an incandescent lamp, since the light of the carbon arc lamp is mostly given by the incandescent crater of the carbon, and the arc stream contributes very little to the light. I call upon Mr. P. C. Hewitt to give an abstract of his very interesting paper.

Mr. Hewitt presented his paper. [See page 59]

PRESIDENT STEINMETZ:—Gentlemen, we have listened to a very interesting paper, outlining the direction in which future work to develop a more efficient means of illumination may proceed. As you have noticed, this lamp requires a practically constant voltage, independent of the current, which means that a steadying resistance would have to be inserted in series to it, just as with the ordinary arc lamp. As I understand, these lamps are operated on continuous current here. I may add that in some experiments we made with this lamp we did succeed in starting the lamp at the voltage at which it was operated without inducing a higher voltage.

The next paper on the program is by Mr. Hammer, who has kindly agreed to discuss a number of interesting features referring to what I have combined under the head of electro-luminescence, phenomena which may lead to improvements in the methods of transformation of electrical energy into light. I give the floor to Mr. Hammer. [See page 67]

Mr. Hammer presented his paper.

PRESIDENT STEINMETZ:—Gentlemen. I believe you will agree with me that we have listened to a series of very interesting papers and discussion is now in order. I call on Mr. Lieb to start the discussion.

MR. J. W. LIEB, Jr.:—Mr. President, I am not prepared to make any remarks on the general field covered in these several papers, but I would like to say just a few words that may be of interest to the members generally, in connection with Dr. Sharp's paper, and a reference in the paper by Dr. Bell to standards of illumination. The standard of candle power on which most of the lamps are being manufactured to-day was practically derived from standards imported some ten years ago from the Reichsanstalt Some few months ago it was desired to check the standards in use generally to-day for the manufacture and sale of incandescent lamps in the United States, to see how closely they agreed with the best standards in use abroad. A number of incandescent lamps that had been carefully standardized and compared with the standards in use in this country, were sent to the Reichsanstalt with the request that the lamps be standardized by placing them in a given position on the photometer, and when giving sixteen candle power, readings be taken of volts and amperes.

Word was received from the Reichsanstalt that they were not prepared to issue standards based upon the British standard candle; their photometric measurements could be issued only in terms of the Hefner amyl-acetate standard. The lamps sent were compared with that standard and the results were communicated to us a few days ago. On comparing the lamps returned, it was found that the photometric value of the lamps representing the standards in general use in this country was within two per cent. of the value assigned by the Reichsanstalt. That is only a preliminary measurement but it is comforting to know that even in the case of such an indefinite standard as the standard of light in commercial use we are progressing very satisfactorily, and that photometric standards in use in different parts of the world on comparison come within such a small limit of error, notwithstanding the fact that a transition coefficient had to be used to make the comparison in terms of the British standard candle. I thought these facts might be of interest in connection with the reference to standards of light in the papers of Prof. Sharp and Dr. Bell.

DR. A. E. WOLFF:—I would like to ask Mr. Lieb whether allowance was made for the fact that the volt as defined in Germany is different from the volt as defined in this country. The Germans adopt 1.4328 volts as the electromotive force of a Clark cell, while in the United States it is legally defined as 1.434 volts. This difference would cause a difference of over 0.5% in the candle-power.

MR. LIEB:—The difference in the standard volt would hardly affect these preliminary measurements, but Dr. Sharp assures me that it has been taken into account.

Dr. A. E. KENNELLY:—The only point that I might mention particularly was the reference of Dr. Bell to the amperes used by the open arc as compared with the enclosed arc lamp. The question of the comparative number of amperes can not be discussed at all. It is altogether a question of energy. When he admits that a 7½ ampere enclosed arc is the equivalent of a 2,000 candle open arc, it is rather a frank admission that for equal energy the arc, everything considered, is equally efficient in either case, which is quite the fact. So far as the color of the arc is concerned practically, it has little bearing on the matter. If we keep within a certain limit of voltage for a direct current arc, say 80 or possibly 90, and for alternating 75 to 80, the purple rays are easily taken care of by selecting suitable glass for the enclosing globe. A clear glass globe will give a very pronounced purple effect, even after it becomes coated with a deposit from the carbon. With what we call an opalescent glass this purple radiation is very largely cut out. That can be very easily proved by throwing a spectrum on the screen and interposing a section of one of the globes which I have in mind. It may very readily be seen how the blue end of the spectrum is cut down and the red end is practically not touched.

Dr. Louis Bell:—With reference to the alleged admission, I certainly admitted nothing of the kind in regard to the efficiency of the lamps. On the contrary, I am prepared to reiterate that all the evidence that has been obtained by scientific photometry goes to show that the alternating arc, so far as the alternating enclosed arc is concerned, is considerably less efficient than the direct current open arc. An immense mass of data has been accumulated by experimenters on this side of the water and the other, and it is absolutely concurrent so far as the laboratory determinations have gone. What I did say, and what I feel very sure of, is that as a practical illuminant in the street the 7½ ampere enclosed alternating arc is fully equivalent to a 2,000 candle power open arc. That is a very different matter from making any statement that the efficiency of the two is equal, because I know, and anybody who has ever put them on the photometer knows, that you have less efficiency in the alternating arc by reason of the lower temperature at the mouth of the crater. The fact is, however, that as actual radiants on the street they are practically on a par. For instance, on the Boulevard, where I happen to live, they replaced the 2,000 candle power open arc lamp by the 7½ ampere alternating arc, and the result was distinctly good in illumination. On the other hand, I have seen various attempts to replace the 2,000 candle power open arc by a 6½ or a 6¾ ampere alternating arc, and the alternating arc was perceptibly inferior. It is when the energy is pushed up that the latter gains in its relative brilliancy, and then it does not come to the same efficiency, but gives a much better distribution, thanks to the absence of the very crater on which the efficiency of the direct current arc depends. As to color, I will gladly bear him out that it is possible by suitable absorbing media to correct the color of the alternating arc. But, nevertheless, it is not as a matter of fact so corrected in any place I have ever seen, and I have seen them in a great many cases. It may be possible to do it, doubtless it is possible. Theoretically it must be. But, as a matter of practice, the lights do not have their color so corrected within a very long distance. They are very far from being white in color, and that I think is probably attributable to the fact that it is almost impossible to get proper care taken of any arc lamp. The result is that the voltage wanders up and down. You find almost from 59 to 90 volts.

Dr. C. A. Doremus:—In connection with Dr. Sharp's paper, one or two historical facts may not be out of place. We owe the original oxy-hydrogen lime light to Dr. Hare of Philadelphia. In 1867 Tessie du Motay discovered and showed at the Paris Exposition a method of preparing oxygen on a large scale. He substituted magnesia, afterward zirconia pencils for the lime. The process was brought to this city in 1868, and oxygen was made on a large scale. A double piping system was carried from Forty-fourth Street down to Union Square. The oxygen was introduced also in Buffalo and there a carburetted street gas was substituted for the pencil. Burners were constructed with a stop-cock, by turning which both gas supplies were regulated; so that if on turning on the gases they did not burn properly, merely turning the stop-cock would bring the amount of the gas and the amount of oxygen to a proper proportion, and a very beautiful light was had. We have at the City College a number of such burners, which date from 1868. Despite the fact that the process worked well on a large scale, circumstances prevented it from being commercially successful in this country. The processes of Brin Bros. and of Mallet make oxygen very cheaply, and recently the fractional distillation of liquid air promises to give us oxygen, the most abundant of all the elements, at a very reasonable cost. So that the future of oxygen illumination in connection either with acetylene or with carburetted gas or with the refractory earths is perhaps as good a one as that of electric illumination.

MR. S. E. DOANE:—There is an interesting matter referred to in Dr. Sharp's paper. The Doctor says: "Photometric comparisons . . . are misleading in that they do not give to the whiter sources credit for the greater visual acuity per candle power which is their due."

In comparing lamps of four watts and three watts per candle, some time ago, it came to my attention (Dr. Sharp and I investigated it later to a small extent) that in the ordinary Bunsen photometer the absorption of light in the paraffin grease spot depends in part upon the color of the light, so that a three-watt lamp, for illustration, in comparison with a four-watt, gives more candles than the photometer indicates.

MR. GEORGE T. HANCHETT:—I had expected that this discussion would bring out numerous methods of distributing light so as to keep the intense radiants from falling directly on the eye. Dr. Bell has dwelt upon this very strongly in his paper, and others have mentioned it also, and I think perhaps it would be of interest to speak regarding an opportunity that I had of witnessing an experiment of this character. It occurred at the Goff Braid Works at Providence, R. I. Mr. Goff, who is an enthusiastic investigator of lighting problems, equipped one of his rooms, which was supplied with spinning machinery, with about ten arc lights. They were the old-fashioned direct-current series type. The current was sent through them in the reverse direction so as to have them burn upside down, thereby throwing the greater portion of their light against the ceiling. Underneath these lamps were placed conical reflectors which entirely hid the arc from any one standing on the floor, and the lamps were placed, I should think, about six feet from the ceiling. The ceiling and walls of the room were painted white with a slight yellow tint. The result was very marked indeed. There were absolutely no shadows in the room and, even underneath the spinning machinery one could see to pick up a small screw or object of any kind, and although the impression after looking first at the lights and then at the floor was that of darkness, by waiting a moment for the iris to adjust itself, one could see to read perfectly in any part of the room.

DR. BELL:—With reference to the very interesting account of that inverted arc method of illuminating which has been tried not infrequently and always with rather successful results, there is one thing you want to watch out for, and that is not to get rid of your shadows too completely, if there is any detail work to be done, where the absence of shadows bothers you. We locate things in space by the light and shade effects. If you get the shade completely out of the way by uniform diffusion over a very large space, it is apt to bother vision quite a little. In fact, I have known one or two instances where draughtsmen complained bitterly of the lack of shadows. But if the lights thus thrown upward are placed a little off to one side or if the construction of the room is such that the diffused light is a little dissymmetrical, that difficulty would be obviated.

PRESIDENT STEINMETZ:—A similar method of diffusing light, at least on the same general principle, I remember was used quite extensively about ten years ago in Europe, by inverting the continuous current arc so as to have the crater on the lower part. There was a large white shade above the lamp, so as to reflect the light immediately from the shade. The luminous radiant now is not the arc but is the shade which receives most of the light from the arc and reflects it. There have been in the last weeks and months various other illuminants proposed, for instance, arc lamps in which materials have been introduced in the arc, as the Bremer lamp, producing luminosity of the arc proper and thereby increasing the efficiency, as claimed, enormously. Perhaps some of you have experimented with this and can enlighten us, and thereby contribute to the facts available in this discussion.

DR. BELL:—I have nothing to add except possibly a single note on the question of selective radiation that has been raised as between carbon, oxides of the rare earths, and a few other substances. The number of substances which give a really selective radiation within the visible spectrum to any considerable extent is very limited. There is some selective radiation in a general way from the material of which the Welsbach burners are made, largely thoria, but the only substances which give markedly selective radiation when heated to a high temperature are erbia and the oxides of one or two, possibly, of the very rare metals which are allied, not with the thorium group, but with the cerium and didymium group, and those are not desirable to use in Nernst lamps or Welsbach lamps. Both of these lamps use principally the oxides of the other groups, which although they give a very brilliant radiation do not show any marked selective power as compared with the oxide of erbium; as to the selective radiation said to exist in the yellow from carbon, the fact that the yellow light appears first is, I think, due to the fact that the eye is more sensitive to yellow light. When you raise a body to incandescence, the first light you see is absolutely without definite color. The light is so dim that there is no action upon the color detecting apparatus of the eye; so that within the range of practical illuminants I think we are going to find that the difference in radiation as regards selective action is so slight that although it may be useful in a minor way we cannot look to it for any broad method of improving our illuminants.

PRESIDENT STEINMETZ:—I might say that moderate selective radiation may occur at very low temperature, as for instance in heat fluorescence, which is really nothing else but selective radiation; that is, at a moderate temperature the body sends out luminous radiation, but it loses this feature rather quickly. I call on Mr. Ryan now to close his paper.

MR. W. D'A. RYAN:—As anticipated, I observed that my statement in regard to the luminometer working within 2 or 3 per cent. was received with some surprise. My statement is based on the results of several thousand observations. Five observers worked simultaneously, making the readings, first approaching the lamp, then receding, in order to counteract any effect due to fatigue and, while the observations of an individual would sometimes exceed the limit stated, the average of 100 observations or more on a lamp did not in any of the several tests that were taken vary more than 3 per cent. from the mean. In order to work as close as this it is necessary to test with the arc in different positions with respect to the carbon tips; that is to say, a set of observations should be made with the arc on the same side of the carbon as the observers, in order to obtain a maximum reading. A similar set of observations should be made with the arc on the opposite side from the observer, thus obtaining a minimum; the mean of the two observations will give the lighting distance of the lamp for the selected intensity. To handle the test properly special provision for rotating the lamp so as to place the arc in the desired direction was necessary, and the practical results and accuracy obtained are far in advance of photometric observations.

MR. JOHN W. HOWELL:—I would like to say just a word or two more about the selective radiation and the radiating character of different substances. The energy necessary to be supplied in order to produce light will vary as the character of the surface varies, so that there is a very material difference in the radiating character of black carbon and gray carbon, although their stability at the same temperature is practically the same. The advantage of the one lies entirely in its radiating character. The projected surface per candle of the black carbon at say 3 watts per candle is about one and three-quarter thousandths of a square inch per candle, while at the same efficiency the projected surface of the gray carbon is two and one-quarter thousandths of an inch per candle. In the Nernst lamp the projected surface per candle at the same efficiency is only about one and three-tenths thousandths of an inch. It is only about 60 per cent. of the surface of the gray filament at the same watts per candle, which shows that its radiating character as an incandescent source of light is very much inferior to the carbon and that its efficiency is due to its very high temperature and to its very high temperature only—I believe not at all to any such characteristic as is supposed to exist in the Welsbach mantle of giving a larger amount of light at a given temperature or a disproportionate amount of light.

PRESIDENT STEINMETZ:—I raised a short time ago the question whether some of the gentlemen could give us information on other methods of illumination proposed recently, as for instance the Bremer arc lamp, the carbide incandescent lamps and some other incandescent lamps. Perhaps Mr. Howell can give us some data in regard to those illuminants, at present very interesting.

MR. HOWELL:—The only one that has come under my personal observation has been the titanium carbide lamp and those lamps which I saw were so poorly made that I was unable to determine the value of the titanium carbide filament. The exhaustion of the lamp was so poor that no matter what the filament might have been, the performance of the lamp could not be good. I expect to get in the course of a few days some more of these filaments and I hope to know more about them in a short time. (Mr. Howell reported later that they were worthless.)

MR. W. J. HAMMER:—The President mentioned the subject of the osmium lamp. I might mention in addition to the few remarks that I have made on this subject in my paper of Feb. 28, 1901, that I had hoped to present something to-night on that subject. For reasons that I cannot state here I was short-circuited in the matter. I think possibly a little later on I may be able to present the matter to the INSTITUTE.

PRESIDENT STEINMETZ:—Gentlemen, if there is no further discussion, we are through with to-day's program and a motion to adjourn will be in order.

On motion the meeting adjourned.

[COMMUNICATED AFTER ADJOURNMENT, COMMENTING UPON CLAYTON H. SHARP'S PAPER, BY T. J. JOHNSTON.]

No flame dependent upon the atmosphere for its oxygen can ever make a satisfactory standard of light: using the word standard in its ordinary sense to mean a source which shall under reproducible conditions emit identical lights per unit of area.

With such a flame there are at least four sources of error, as follows:

A. Variation of temperature of the illuminant;
B. Variation of composition of the illuminant;
C. Variation of temperature of the oxygen supply;
D. Variation of composition of the atmosphere.

Some years ago I made many photometric observations of naked flames and of flames of the argand type, having an ordinary cylindrical chimney, using an amyl-acetate standard; these were all of commercial illuminating gas. The amyl-acetate lamp was not calibrated, being furnished by the maker with the photometer. For the purposes of this communication these facts are unimportant.

I found evidence of perceptible variation in candle power within ordinary ranges of temperature. I have not at hand the particulars of the tests, but speaking from memory, the variation was about 4/10 of a candle power in 16 for a difference of 40° in temperature of the illuminant and its atmospheric supply. When I first suspected this variation I made the following test:

A tank was filled with compressed gas and exposed to outdoor temperatures until the thermometer attached to it registered approximately 30°F. The tank was exposed for several hours and when gas was released from it on the bulb of a sensitive thermometer, which had been exposed for the same length of time, it caused no variation of the mercury. The candle power of the gas was taken under these conditions at 15.6 ±; the air supply was at external temperatures, or about 30° F. This test was made with as much rapidity as possible. The reservoir was then sealed off and allowed to stand until it had attained the temperature of the testing room, 70° F., and for several hours afterward. Candle power was then taken; with external atmospheric supply at 30° F. the candle power was 15.9 ±; with air-supply from the testing room the candle power was 16.1 ±. These tests were repeated a number of times with substantially similar results.

I did not at that time have facilities for making careful analysis of the illuminant used or of the atmosphere, and it is doubtful whether I had the technical skill to analyze gases with the required accuracy. I did, however, purposely adulterate the illuminant with known percentages of carbonic acid gas and sulphurous acid gas and this showed, as has been pointed out by gas chemists and engineers many times, that minute quantities of these produced disproportionate variations in candle power. The average of a number of tests showed that 1 per cent. of carbonic acid gas produced 10 to 12 per cent. reduction when mixed with the illuminant; the same proportion of sulphurous acid gas produced from 5 to 7 per cent. reduction. When mixed with the atmosphere supplied to the illuminant the reduction of candle power was in almost exact proportion to the adulteration.

All of the above results were, I think, subject to considerable errors, and the only safe general deduction from them is that a gas flame could not be taken as a standard when supplied with oxygen from the atmosphere. In view of this, Dr. Sharp's paper seems to present an alternative in the use of a gas illuminant of known composition supplied with a combining gas also of known composition, and which may be burned under known and definitely reproducible conditions.

Assuming that calcium carbide and water may be produced chemically pure, or at least sufficiently so for commercial results, and that oxygen may with reasonable certainty be so produced, it seems that we ought to be able to produce a light which would be strictly a standard, always provided that means are employed to keep the temperature within a limited range, though many difficulties still remain to be overcome.

DISCUSSION AT CHICAGO, JAN. 3, 1902.

THE CHAIRMAN (MR. R. H. PIERCE):—Dr. Bell's paper ends with the words, " to be continued," and I imagine, from the conclusion, that he proposes to take up various new things in electric lighting, and among them the Nernst lamp to which he refers. In what he has said he has shown enough of the general principles of illumination to enable us to anticipate the conclusions which he will draw. This is a subject I have often discussed and often heard discussed among people who have had to solve problems of illumination in a practical way. I have never seen it formally presented in this same manner before.

MR. VAN RENSSELAER LANSINGH:—Dr. Bell mentions the equation $N = c\,P/5\,\pi$. It seems to me that gives a very low figure. If we use a 16 c.p. light we have a radius of practically 1. I suppose the unit is the inch. A 2-inch diameter sphere enclosing a 16 c.p. light would be, I think, altogether too brilliant. If we use a dense diffusing globe, and cut down the light to one-half what an ordinary clear globe gives, I think even then we have too large a unit of light for good diffusion. These lights in the ceiling are using about 1 candle power per 6 square inches of surface.

THE CHAIRMAN:—On the preceding page he fixes the minimum area for a given candle power at 5 c.p. per square inch. Then on the next page he says this should be at least that radius. I presume you would agree with him that it ought to be at least that.

MR. LANSINGH:—Yes, and a great deal larger, because that is even less than the ordinary bare bulb. These lights here are almost too brilliant. I certainly would not recommend anything more brilliant than these. That is, anything that comes directly in the field of vision.

THE CHAIRMAN:—Is that not consistent with what he said on the other page?

MR. LANSINGH:—It is consistent with what he says, but I do not agree with him.

THE CHAIRMAN:—I see Mr. Lansingh is too modest to draw the conclusion which seems to be apparent from Dr. Bell's paper, but it is evident that any kind of electric light we now have has too great intensity to be used in the line of vision. The clear, open globe arc lamp has already become practically obsolete. It is a thing of the past, and I do not think it is at all radical to say that the time is near at hand when we will see no more clear glass open incandescent lamps inside than we see clear globe, open arc lamps outside, except where they are used simply to produce a dazzling effect on the eye. They will use them, probably on State street along the edge of the show windows and in electric signs, but for the purpose of illumination there is no reason and has been no reason for a good many years, why any one should use a light of such intensity as this in the line of sight. I am glad to see this paper for the reason that I have been preaching this same doctrine myself and applying it, that is, where I have my own way, and I think there has been a great tendency in the last year to discriminate, not only between the brightness of illumination, but also between the illumination and the actual effect which is produced. I forget Dr. Bell's happy expression for the term, but we all understand what it is. When we look at one of these lights our eyes work like a shutter and put on the 64 stop, and we cut out a corresponding part of this light and use the rest to see something with. We are unwilling to go to work and cut out 10 and 20% by diffusing it, and we allow our eye to cut out 75% of it. The eye adapts itself to the light. Illumination is " all in your eye." I have put in illumination on the basis of 3,600 square feet per 16 c.p., and I have put it in on the basis of 9 square feet per 16 c.p. They were both satisfactory.

Dr. Bell's paper is really an introduction to this whole subject. This matter is also taken up more specifically by the other papers, and will be taken up extensively in discussion at New York, I presume.

The next paper, " A Note on an Acetylene-in-Oxygen Flame," by Clayton H. Sharp, describes another method of obtaining an absolute standard for measuring light.

The paper, " The Present Status of the Question of a Standard of Light," by Clayton H. Sharp, seems to conclude at the end of the paper that the incandescent lamp is the best thing with which to measure the candle power of incandescent lamps. I think all of us who have done any amount of photometric work, especially on a commercial basis, will agree with that conclusion. A few years ago we got standards from every lamp manufacturer in the United States, and it was quite interesting to make comparisons.

Mr. W. D'A. Ryan has summed up the whole of his paper in about half a page. His first conclusion is a comparison between the open and closed arcs. The open arc is practically obsolete; there will be no discussion on this point. I tried about a year ago to get a dollar apiece for 1,700 open arcs which were as good as new, and I could not get it. The open arc has been weighed in the balance.

Referring to his fourth conclusion, I would like to say that the term " effect of good lighting " is ambiguous. To some persons good lighting is something that produces a dazzling effect on the eye of the stranger when he comes to town. You can see this effect along State street, where in some of the windows the lights are in sight and very brilliant, while in others the lights are out of sight, producing a much softer effect.

PROF. P. B. WOODWORTH:—The question of illumination is, without any doubt, one of the most important topics we have at the present time. We in America have deservedly been the laughing stock of the people in Europe on the way we use our lights. I once had the pleasure of calling on a European scholar in his study, and found he had his table illuminated with two candles, one at each side. I asked him how it happened that he was getting along with such a small amount of light. He replied that I was an American and lived where people ruined their eyes by the use of too-brilliant lights; that he had had no trouble with his eyes. He also said he could generally tell Americans from other people as they usually wore glasses

Referring to what Mr. Pierce said about illuminating windows for spectacular effect, go down State street and notice some of the windows that are lighted with incandescent lamps. In some of the windows the clear incandescent lamps stand right out, and then notice windows where the lamps themselves are not seen at all, but the goods in the windows are displayed. In one case you get an effect of light, and you might say " here is a man who is doing a lot of advertising by incandescent lamps." It is almost impossible to see anything in the windows on account of the brilliancy of the lights. In the next case, where the lamps are out of view, you are impressed with the beautiful effect of the light display in the window.

PROF. MORGAN BROOKS:—There is just one point that I might bring out, the advantage of general illumination of offices. I think you have all noticed the custom of bookkeepers who work at night, to have but a single light suspended over the desk and no other light in the office. It is a mistake not to have some general illumination in the office, so as to rest the eyes when suddenly lifted from the work. When the line of vision is thrown from a bright light into almost darkness, the eye has to accustom itself to this change, which requires effort. There should be a smaller amount of direct light and more diffused light; in other words, a uniform light. Instead of using an opaque reflector, it is much better to use a porcelain shade, so as to give general illumination. A small piece of white paper on a black board is more trying to the eye than if the board were white. The eye sees fine lines and recognizes them clearly enough, and that does not cause contraction of the pupil. Too much contrast outside of the actual field of view is objectionable, as it tries the retina more than is necessary.

THE CHAIRMAN:—That calls attention to one point which has been overlooked in this paper—that is, that the best illumination is that which is the most uniform. The first thing in laying out a practical job of lighting is to make the standard as nearly as possible uniform, because the eye will accustom itself to the standard. The eye will adapt itself to a bright or a dark day. Uniformity is what we want.

MR. LANSINGH:—I do not think absolute uniformity is to be desired. It would not allow us to judge of shadows. We judge of the distance of objects and the shape by means of shadows cast. Take, for instance, a bright day, when there is a very hazy cloud in the sky, giving a perfectly diffused light. The sun, we will say, is not visible, but yet it is very trying on the eyes, and it is very hard to distinguish objects, not only as to their distance, but also their shape. We get the same effect on a foggy day. If we had perfectly diffused light and perfectly uniform light, I do not think it would be altogether advantageous.

THE CHAIRMAN:—Your clear blue sky is perfectly uniform light. The difference is in diffusion, not in uniformity.

MR. LANSINGH:—We do not get perfect uniformity of illumination on such a day on account of shadows cast by different things. The most perfectly diffused light is on such a day as I spoke of, when the light is most uniformly distributed. You can see the sunlight is similar to open arcs in some respects, but when you put an open arc in an opal globe, and get perfectly diffused light, you get more the light that you get on a hazy day.

THE CHAIRMAN:—As a matter of fact, I am inclined to think that the greatest uniformity we can produce artificially does not approach what we get with the kind of light we get in the daytime.

MR. LANSINGH:—I agree with you. It is more a theoretical point, I presume.

THE CHAIRMAN:—Mr. Lansingh, I suppose of all the gentlemen here this evening, you are perhaps the best qualified to speak on one subject referred to by Dr. Bell—that is, the lowering of the intensity of the source of illumination. I think we would be interested to know what standard, if any, he has used for that purpose.

MR. LANSINGH:—I do not know of any standard being used in general. For my own practice I have adopted five to six square inches per candle power for general illumination. That applies usually to low rooms and it cannot be taken as a standard in every case, by any means. For a room like the present one, I adopt such a standard. A 16 c.p. lamp is supposed to give 16 c. p. in its horizontal intensity. I wish to call attention to one more point with reference to the shade. It is swinging slightly now, and that is the general condition in which such shades are used, supported by a cord. If you should hold a piece of white paper underneath it, you would find that there are parallel white lines and streaks passing over that paper, and those are extremely hard on the eye. That has the same effect as unsteadiness. A shade only intensifies the lines which are naturally inherent in the bare incandescent lamp. For that reason all forms of such shades are very hard on the eye.

THE CHAIRMAN:—I would like to ask if anyone has had anv experience in measuring candle power of Nernst lamps.

MR. W. B. HALE:—I measured one of the Nernst lamps, the German make, a few days ago, and obtained a maximum of 68 c.p. horizontal, with 100 watts. That was an efficiency very much higher than ordinary incandescent lamps—about .9 of an ampere to 110 volts. In the Nernst lamp the heating coil obstructs a large part of the light.

PROF. WOODWORTH:—That is in the German lamp. The American lamp does not do that. It has a heater above the glower which is more efficient than the German spiral, and at the same time assists in the reflection of the light.

[Adjourned,]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, January 13, 1902.

The annual dinner of the INSTITUTE was held this evening at the Waldorf-Astoria, the guest of honor being Mr. Guglielmo Marconi, the distinguished Italian space telegraphy expert. The brilliant assemblage of guests, numbering nearly 300 members and ladies, among them some of the foremost men in the various professions, made the occasion one of the most successful ever arranged by the INSTITUTE. The Astor Gallery, where the dinner was held, was decorated with novel and beautiful effects. Along one side of the room under a huge American flag, was a big table upon a dais; at the table were seated President Steinmetz, Past Presidents Elihu Thomson, Alexander Graham Bell, Francis Bacon Crocker, Frank J. Sprague and Carl Hering; Sir Percy Sanderson, C.B., the British Consul General; Cav. Branchi, the Italian Consul General; Dr. M. I. Pupin, William Stanley, Charles W. Price, Arthur Williams and the toast-master, Past President T. Commerford Martin. The menus were made interesting by clever sketches of Marconi staffs on the coast lighthouses, signalling " ss " in three dots, all the way across the ocean. By means of flexible conductors and tablets, the room was decorated with hundreds of electric lamps, while very small green lamps were inserted in great coils of the conductors upon the tables. On large tablets at either end of the dining hall were the names " Poldhu " and " St. Johns," in letters formed of electric lamps, and opposite the speakers' table was another tablet bearing the name " Marconi." In strands of the conductor which was strung so as to connect the three signs, were inserted clusters of three lamps at frequent intervals, designed to represent the three dots or " s " flashed by Mr. Marconi's assistant across the Atlantic from the coast of Cornwall to Newfoundland. These were flashed now and then or allowed to remain lighted, forming an appropriate and novel feature of the dinner festivities. In keeping also with the spirit of the evening was the procession of waiters carrying assorted ices, which were formed in semblance of electric lamps and automobiles grouped at the bases of telegraph poles. From these poles dangled broken wires,and between tho poles were carried ships and other symbolic designs. All of these features were loudly applauded by the guests at the tables and in the galleries.

After dinner was over, President Steinmetz greeted the guests and cordially welcomed Mr. Marconi.

PRESIDENT STEINMETZ :—Ladies and Gentlemen : It is extremely gratifying to me that I am enabled to greet you at this, the annual dinner of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. I believe I voice the sentiments of all when I say that we are extremely sorry not to have with us the grand master of our industry, Mr. Edison, who from the early days of our profession has been working with us, and is still actively engaged in pioneer work of highest importance; he who has, I may say, founded our industry and has been principally instrumental in developing it and thereby enabling us, who constitute the profession, to be what we are at present.

I am glad, however, to introduce to you to-night another genius; an engineer who has been distinguished on both sides of the Atlantic by his work; who, taking up where Mr. Edison left off in the beginning of his career, has advanced beyond what others have done. While telegraphers have sent their messages through wires over the country or through cables across the Atlantic, and telephony has made talk possible over great distances; Mr. Marconi, our distinguished and honored guest, has done more. Instead of sending messages across the seas by cables, he has succeeded in sending them across empty space through the luminiferous ether.

I am glad and very thankful that we have with us this distinguished guest from abroad. I do not need to dwell any further upon this because we will have the pleasure of listening to him after a very short while, and I understand that Mr. Marconi will give us an explanation of what he has done and of what he hopes to do in the near future.

I now will turn the chairmanship of this meeting over to Mr. Martin as toastmaster. I hardly need to introduce Mr. Martin to you, because you have known him for years and years as a toastmaster. While presidents come and go and other officers of the INSTITUTE, Mr. Martin's efficiency as a toastmaster, as we all remember from many enjoyable social gatherings, has been so prominent that nobody has ever been found who could anywhere nearly equal his mastery; and, if you do not believe this, you will see for yourselves how true it is. (Laughter and applause.)

TOASTMASTER MARTIN:—On such an eventful, memorable and delightful evening as this in the history of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, there is fortunately very little left for the toastmaster to do. In company with the rest of the committee, he has simply been loafing and idling during the last forty-eight hours. (Laughter.) We were not quite sure when Mr. Marconi would get through in Canada, or whether he was going to Vancouver, or was about to try experiments on the Pacific Ocean. When we succeeded at last in locating him, we had barely forty-eight hours left us in which to organize this banquet. On behalf of the committee, and particularly of Mr. Calvin W. Rice, our Chairman, I beg you to accept our most profound and humble apologies. We have done our best. (Applause.)

The first duty which devolves upon me this evening is to read to you various communications which have been received by our committee. One, which is in autograph, and a fac simile copy of which I think everyone here would like to have, is as follows:

I am sorry that I am prevented from attending your annual dinner tonight, especially as I should like to pay my respects to Marconi, the young man who had the monumental audacity to attempt and succeed in, jumping an electrical wave clear across the Atlantic Ocean.

Yours,

EDISON.

It was absolutely impossible for Mr. Edison to be with us tonight, but he said he would be thoroughly well represented when he sent his better half, (Applause). I may add that within the last ten days I had the pleasure of speaking to Mr. Edison himself with regard to Mr. Marconi, and he said that he had thought that sometime or other there might be signals flashed either way across the Atlantic without wires, but that he did not know when, and being pre-occupied, he did not think he would have time to do it himself, and he said to me: " Martin, I'm glad he did it. That fellow's work puts him in my class. He is a worker. It is a good thing we got him young."

Gen. Miles, the Commander-in-Chief of the United States Army, was to have been with us this evening, indeed, he accepted our invitation; but later he found it impossible for him to leave Washington, and he sent this evening a personal message to Mr. Marconi, and also to the INSTITUTE through Col. Samuel Reber, one of our officers, in which he desired him to express his great regret at his inability to be present, and his pleasure in knowing that we were extending this honor to Mr. Marconi as our guest.

I now have the pleasure of reading the following which is headed "City of New York," and is from the office of our wireless Mayor. (Laughter and prolonged applause).

I am sorry that it is not in my power to attend the dinner of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to be given this evening, at which Mr. Marconi is to be the guest of honor. The results already obtained by Mr. Marconi mark him as a man who has been a benefactor of the race, and his latest achievements seem to give promise of still greater services to mankind. I wish it were possible for me to be present to say to him in person, on behalf of the City of New York, how highly his scientific labors are appreciated. Asking you to convey to him my regards and best wishes, I am, respectfully,

SETH LOW,
Mayor.

I hold before you, fellow-members of the INSTITUTE, the record of the dinner given to Cyrus W. Field in this city thirty-five years ago, when, after labors that were superhuman and devotion and courage that were almost immortal, the Atlantic cable had at last been finally and successfully laid. Mayor Low's father presided at that dinner, and this is Prof. Morse's own copy of the record. I thought it would be interesting to bring it out of my little collection this evening and put it on the table.

The following letter has been received from the President of Columbia University:

I regret deeply that a previous engagement for the evening of Monday will debar me of the pleasure of accepting the invitation that I have received from Prof. Sever to be present at the dinner tendered by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to Signor Marconi. I greatly regret my enforced absence for I should enjoy being able to join in your tribute of respect to the distinguished inventor, and in felicitating him upon having placed his name on the roll of the great discoverers and the great benefactors of the human race, for there appears to be every reason to believe that the most important practical results will follow in due time from Signor Marconi's successful experiments. Pray tender to your distinguished guest an expression of my sincerest congratulations and high regard, and believe me,

Very truly yours,

NICHOLAS MURRAY BUTLER

From Capt. Chadwick of the United States Navy, whose name is remembered whenever we celebrate American victory and American valor, the following was received:

I greatly regret my inability to attend the dinner in honor of Mr. Marconi. It would afford me great pleasure to be present to give in evidence my esteem and regard for him. I know him well enough to know that his genius is equalled by a modesty and reticence of statement, for which I have an equal admiration with the best. When he told me last Spring of his hopes, I knew he would do more than he mentioned. The result has more than justified expectancy.

F. E. CHADWICK.

I will also read the following letter to Mr. Rice as Chairman of the committee:

Replying to your kind invitation which was delivered during my absence from the city, I beg you to transmit to the INSTITUTE my thanks for the honor proffered. I feel that I could not rise to the occasion, and regret not being able to contribute to the pleasure of the evening; but I wish to join the members in heartily congratulating Mr. Marconi on his brilliant results. He is a splendid worker, full of rare and subtle energies. May he prove to be one of those whose powers increase and whose mind feelers reach out further with advancing years for the good of the world and the honor of his country.

Yours very truly,

NIKOLA TESLA.

Permit me to say, gentlemen, even if it be a personal allusion, that from my beloved friend Tesla these ten years gone, I learned to believe that it would be possible to do what Mr. Marconi has now done.

As you are doubtless aware, our esteemed friend, Mr. George G. Ward, Vice-President of the Commercial Cable Company, is the representative in this country of the Institution of Electrical Engineers of Great Britain, of which our guest this evening, Mr. Marconi, is a member. I have received the accompanying letter from Mr. Ward, from which you will gather that he still believes in the laying of submarine cables.

Your letter of January 10th, conveying the kind invitation of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to join with them on this Monday evening, was delivered while I was away from the city, in Washington. I regret to say that I am unable to accept the invitation. I am compelled to return to Washington this afternoon to attend to matters in connection with the laying of the Commercial Pacific Cable. I congratulate the society upon its distinguished guest. I am very sorry I cannot be there to meet him.

Yours very truly,

GEORGE G. WARD.

I wish to say that Mr. Ward called me up on the telephone and asked me to take Mr. Marconi by the hand and shake it, and say that everything that would further the cause of communication between the hemispheres he was with and for.

Mr. Marconi had the distinguished honor of being born an Italian. I have had handed to me this evening by the Italian Consul in this City, a message which he has received from the Italian Ambassador to this country, which it will afford me great pleasure to read to you.

Absent because of previous engagements of importance from the dinner which the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS gives in honor of Signor Marconi, I beg you to offer my assurance that I am present in spirit and rejoice in the sympathy shown for our illustrious countryman who adds his own to the other great Italian names of Volta, Galvani, Pacinotti and Ferraris in the history of electrical science. The new invention of Signor Marconi whose development will unite more and more firmly the new and old world in all their relations, is really an inestimable victory of human genius over the forces of nature; a noble conquest of civilization and mankind. I salute my glorious compatriot, and thank the worthy and high honorable Association which so fraternally welcomes and lauds him and his achievement.

THE ITALIAN AMBASSADOR TO THE UNITED STATES.

If you will look at your menus, gentlemen, on the second page you will find enumerated one or two of the European societies to which our guest of honor belongs. We have deemed it fit and appropriate that with them this evening we should exchange fraternal greetings, and one of the officers of the INSTITUTE, in conference with President Steinmetz, has prepared, with the permission of Mr. Marconi, cable messages, which, with your approval and consent, we shall take pleasure in forwarding. I have pleasure in calling upon one of our members, not less well-known in Italy than in this, his own, country, Mr. John W. Lieb, who was associated with the Edison Company in Milan for years, to read you the despatches which it is proposed to forward.

Mr. Lieb then read a series of cablegrams to be sent to the various foreign organizations with which Signor Marconi is associated, and, on motion, the Secretary of the INSTITUTE was authorized to forward the same on behalf of the Society.

THE TOASTMASTER:—A distinguished English architect, when asked what his monument might be, and, in fact, it was afterwards inscribed as his epitaph in St. Paul's Cathedral, London, said, " Look around you." In introducing the guest of honor this evening all that I will say, gentlemen, is, look at these illuminations around you and three cheers for Signor Gugliemo Marconi. (Loud applause.)

SIGNOR MARCONI:—Mr. President, Ladies and Gentlemen: I can hardly find words to express my gratitude and thanks for the reception I have had here to-night. I thank you very much for the appreciation of the work which I have been fortunate enough to carry out. I feel myself highly honored to be entertained by such a great body as the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. I think it is well-known all over the world that Americans stand first in applied electrical engineering. I feel myself greatly honored to be among so many eminent men, whose names are household words in the whole civilized world.

With your permission I will give you a brief description of what my system has at present accomplished, especially in reference to use on ships, and what I hope it will accomplish in the future. Wireless telegraphy is now attracting very great attention all over the world, and its progress is not slow. Five years ago the system with which my name is identified was working over a distance of about two miles, but its range has been rapidly increased until a few months ago it was quite possible to communicate by means of an improved and attuned system over a distance of 200 miles. The commercial application of the system has been given serious consideration, and improvements of importance have been made.

It may interest you to know that the commercial application of the system has been tried in Great Britain, its chief base being in England. It may interest you, also, to know that there are over seventy ships carrying permanent installations for wireless telegraphy. Of these thirty-seven are in the British Navy, twelve in the Italian Navy and the remainder are on the large liners, such as the vessels of the Cunard Line, the North German Lloyd and the Beaver Line.

There are over twenty land stations equipped in Great Britain and on the Continent of Europe, which work in connection with the ships, and several on this side of the water, and a certain number of Lloyd's signal stations are now being equipped.

I regret very much that it is impossible for me in a brief address to go into the scientific details or into the historic development of my system, but I would like very much to reply in some way to the questions that are constantly asked as to the practical working of this system. I think I am right in saying that it is the general belief that when a message has been transmitted, or, as we might say, has once been entrusted to space, anyone with an appropriate receiver will be able to take it up and thereby find out what the message is and other people's business. This, in a commercial enterprise, would be very awkward, because nobody would like to send messages, and certainly commercial messages, such as stock quotations or private messages, if they thought that other people would get hold of them. By experiments and improvements which have been made, messages can only be read when the receiver and the transmitter are attuned. This perfected system is not at present in use on the ships. It has been deemed necessary that each ship should be equipped with apparatus which will permit of its reading a message sent from any other ship, because of the possibility of aid being required in distress. Therefore, the apparatus on all ships is attuned so that one ship may call up any other ship; but it is practicable to have the apparatus so attuned that the messages transmitted can in no way be received by any other apparatus except that attuned to receive the message.

In the case of transmissions from land to land, or across land, what we call the attuned system must be used. I will refer the technical gentlemen, who are here present, for details as to my work on that subject to a paper published by the Society of Arts in May of last year. With reference to what has already been accomplished at short distances—what I call short distances is up to two hundred miles—I refer you to some remarks which I will read, made by Prof. A. Fleming, who is professor of electrical engineering in London University, and who is well acquainted with the wrokings of my system. In a paper that he read on "Electrical Oscillations and Waves" before the Society of Arts in December, 1900, he said: 'Communication was established by the Marconi system for the Admiralty between Portsmouth and Portland, two places about sixty-five miles apart, in a straight line, having hills eight hundred feet high in the line of sight. Across this line of communication, and included in it, there is another thirty-mile Marconi circuit between stations. These two lines cross each other at not a very great angle. By the employment of properly attuned receiving and transmitting circuits, it has been found possible to render these circuits quite independent of each other, so that no messages which go on between either two of the stations can interfere with messages being sent between the other two stations. What has been done here can be carried out indefinitely, and the objections as to interference of stations which uninformed persons are in the habit of raising, with regard to the system of wireless telegraphy, as a matter of fact no longer exist."

I have mentioned that I found it possible by means of the attuned system to transmit messages a distance of two hundred miles. Transmission was obtained between stations in England and Ireland, even in cases when a very small amount of energy was used—perhaps only as much as a very small incandescent lamp. That was found sufficient to telegraph two hundred miles. But it was at once thought that by the rational application of large amounts of energy, which electrical engineering has taught us how to produce with ease and to utilize, it would be possible to transmit messages to a much greater distance than had heretofore been dreamed of, or found possible. With the intention of demonstrating that trans-Atlantic transmission was possible, two comparatively very powerful installations were set up, one in Cornwall, Eng., and the other at Cape Cod, Mass. Prof. Fleming,of the University College in London, assisted me greatly in the installation of the powerful machines required. An unfortunate accident, which was caused by a hurricane at Cape Cod, partly demolished that station and for a few months at least, caused the postponement of the tests which I intended to carry out between England and the United States.

As I did not want to wait until repairs were effected at Cape Cod, I thought it might be useful in some way to get the English station to transmit with its full power, and the messages to be received on this side by means of a temporary installation; and as I did not think it prudent to try such a distance as three thousand miles at once, I thought that this temporary installation, this first shot of getting messages across the Atlantic, should be tried on the Island of Newfoundland, at St. Johns, which is about two thousand land miles from England. Instead of poles, as are generally used for permanent work, kites and balloons were employed to elevate the aerial wires, the necessity of which I think you are pretty well acquainted with. These kites or balloons gave a great deal of trouble, as, owing to the tempestuous weather which prevailed in Newfoundland last December, it was found almost impossible to raise the kites or balloons to the required height. However, I am glad to say that at certain intervals, on the 12th and 13th of December, the kites were for a short time got into satisfactory position, and my assistants and I had the great satisfaction of receiving a number of the prearranged signals from Cornwall, at the right time and at the prearranged speed. (Applause and cheers.)

Experiments would have been continued in Newfoundland with a more permanent installation, as I at once recognized the unsatisfactory results which were obtained by an installation which depended on the wind and weather,which in those northern regions are very unreliable in winter; and this permanent installation would have been set up, had I not discovered the fact that the Anglo-American Telegraph Company has, or claims to have, a monopoly of all telegraph communication in that colony (Laughter); not only has it got the cable and ordinary communication, but it claims to have the monopoly of preventing anyone from trying experiments which are connected with telegraphy in that colony, and in a certain way claims to have a monopoly of the air and the sea. (Laughter.)

It is rather strange, I may mention, that in England the British Government has the monopoly of the telegraph, and I am glad to say that it has encouraged my experiments rather more than prevented them. Certainly, when it comes to commercial work between stations in England—not between stations in England and ships, but between stations in England—we have come to a suggested arrangement; and I do not think the British Government would have thought of interfering with experiments, the object of which was the advancement of science. In Newfoundland, although we were not interfering with the revenue, but rather increasing it, due to the cabled results of my experiments and of what was going on (Applause), I was told by the manager of the cable station at St. Johns that he was pleased that I had provided a revenue for the company, because during the three days I was there they sent fifty thousand words over the wire. Still, we had to stop, and I do not think it wise to put up a permanent installation there.

My colleagues in the electrical profession well know, and in other professions too, that it is difficult enough to push a new thing when it is practically unimpeded, and that it becomes almost an impossibility when you have got to face injunctions and threatened injunctions.

Well, under the circumstances, I thought I would cross over to a country that is not very far from Newfoundland, about ninety miles away, Nova Scotia, part of the Dominion of Canada; and I think that a permanent station will be erected there, and that the one at Cape Cod will be repaired, and I am confident—perhaps inventors sometimes, or what are called inventors, are over-confident—that it will be possible to transmit messages, and perhaps several messages across the ocean at the same time, and in a commercial and sure manner.

I wish to state here before you all that I am very greatly indebted to the governments of Newfoundland and Canada for the encouragement, sympathy and assistance they have given me in my work, and I trust that the future results will bear out our hopes and expectations.

I think it is generally admitted that modern history has proved beyond a doubt that one of the greatest factors of civilization in all the progress of the world is the facility with which people living long distances apart can readily and quickly communicate with each other. If my system can be commercially established, which has yet to be proved on long distances, between the different parts of the earth, it will not fail to bring about a further great cheapening of the methods of communication. An installation that will work across the Atlantic, however elaborate, costs only a very small fraction of what a cable costs. At present the great cost of the cables themselves and their heavy working expenses, causes the existing method to be beyond the reach of the majority of people inhabiting the various countries, but I believe that should my dream be realized and this new method be applied, the cost of cabling to distant countries will be very greatly and substantially reduced. A cheap telegraphic service between united families, however scattered, would keep the dispersed members in close and constant touch with the old home, and would cement friendships between the people of this great nation and the other nations of the globe—forging another link in the ties which bind this country to Great Britain. (Applause).

Time has not permitted me—I have said this before—to make any reference to the history of wireless telegraphy. I wish you to know how much the success of my work has depended upon the work of my predecessors and my present assistants. I have built very greatly on the work of others; and before concluding, I would like to mention only a few of the names; I may omit some, but these occur to me at present. They are Clerk Maxwell, Lord Kelvin, Prof. Henry and Prof. Hertz. (Applause.) I do not know if you are all aware of it; I think it has been well published in the daily press, with more or less accuracy, that these messages were received on the telephone which was actuated by the impulses translated through it from a coherer which was influenced by the electric rays coming from England, and I wish to mention the name of Prof. Alexander Graham Bell in that connection. (Applause.) If it had not been for the invention of the telephone, I do not know whether at this day we would have received signals across the Atlantic. They might have been received later, with a great deal more power. An ordinary recording instrument was not sufficiently sensitive to work at that distance, but, by the aid of the telephone, it did work.

Gentlemen, I can hardly express how grateful I am for your hospitality and the kind references which have been made to my work. I hope that I can bring this work to a successful completion. As a stranger here, I thank you very much for your hospitality, and now I have the honor to drink the health of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Mr. Marconi took a glass from the table, holding it high above his head, then lowered it to his lips, and the diners doing the same, drank the toast in silence.

THE TOASTMASTER.—When on Sunday last your committee had the honor and pleasure of meeting Signor Marconi and telling him that it was " up to him," they had a very quick appreciation of the fact that when he came before you this evening he would justify the expectation which we entertained when we desired his presence among us to-night as our guest of honor. And when, during that long and laggard leisure which was at the disposal of your committee in making the arrangements for this banquet to-night, we cast around in a desire to rally the best spirits in the INSTITUTE about us, needless to say, our first thoughts turned to New England and to Prof. Elihu Thomson. While Prof. Thomson lives in New England, in these days of rapid transit that is no impediment to New York citizenship. We have understood that either to him, or to Mr. Lockwood, is attributable that remark of a Bostonian, living somewhere within the periphery of the Hub, that one of the best things about Boston was the 5:30 express for New York. Prof. Thomson knows that whatever train he takes for New York, he is equally welcome—with due respect to the New York *Sun*—in our midst.

Prof. Thomson and myself, and one or two others, around this board to-night, have somewhat of a reluctance in uttering the phrase "Anglo-American"; but, gentlemen, as you know, this country, in the cordiality which it extends to talent and genius of every kind, has not drawn the line at the little island that sits within the seas, but has welcomed the old and great continent of Europe. When Signor Marconi came to this country he also had a whole continent, presumably, at his disposal; but he went to Newfoundland, seeking a bluff. (Laughter.) He found it. Then, turning his eyes eastward and southward, the next Anglo-American promontory upon which his eager and anxious gaze fixed was in the vicinity of Boston, but, to his intense disappointment, he found that it was occupied and pre-occupied and that the golfers of Boston were teeing off from Bunker Hill. (Laughter.)

During this evening he has received word from Cape Cod that the Government is willing that he should use that as a coaling station. (Renewed laughter.) He had already had extended to him the genuine and fervent hospitality of our distinguished past President, Alexander Graham Bell, who said "Here is my property at Cape Breton, come and own it for yourself." But southward still was his cry, until he reached New York City, having heard that within this bailiwick and enjoying the freedom of the city, which has been extended to him by our Mayor, he could find a place, not far from us, where perhaps exist the steepest bluffs to be found along the Atlantic coast, to which he may now have the reversion, and which in his honor we will name *Mar*coni Island. (Laughter and Applause.) Now, fellow members, had this been an American addressing an English audience, I should have said you were rather slow.

Prof. Elihu Thomson is not only one of our most distinguished Past Presidents, but, you will agree with me, one of the most distinguished electrical engineers this country has ever produced (Applause), and when at our brief bidding he comes as others have come, hundreds of miles to join with us in our greetings and acclamation to the guest of honor this evening, we can all feel deeply pleased and gratified at the earnestness he has shown in joining with us in this celebration. I have now the greatest pleasure in calling upon Prof. Thomson.

PROF. ELIHU THOMSON:—Mr. President, Ladies and Gentlemen: I am sure your toastmaster has done more than justice to myself; in fact, he has so treated me that my modesty almost compels me to sit down and say nothing. Inasmuch as I have made this long journey from the hub of the universe to one of the outlying stations, I surely shall try to do my best on an occasion of this kind.

We are present here this evening to do honor to a gentleman who does us honor in coming here and presenting to us in the simple, straightforward manner in which he has spoken, the results of his great work. I think I can speak for you all in saying that we are intensely gratified that he has been able to do this for us. Our feeling of gratitude is almost beyond our powers of expression. We realize perfectly the many difficulties which he has had to contend with. We know that pioneer work in any field is not by any means easy. It is always hard work. It is not easy to set going these forces and get valuable results. His last achievement reminds me of a school boy companion whom I lost sight of for a very short time. He was one of the smallest fellows in the class. When I next saw him he was about six feet tall. Such was my idea of wireless telegraphy a short time since. It was a small thing but had possibilities of growth. But all of a sudden it jumps to a height that we did not dream possible. In other words, it jumps across the Atlantic ocean. Marconi went quietly to work and laid his plans. and, without saying a word to anybody, got ready to make this supreme test, and when he made it, succeeded in doing what he might be expected to succeed in doing, provided, of course, he had everything at his command conducive to the result—in other words, command of enough electrical energy and a confidence in the working of his apparatus, which comes only from entire familiarity, and as one may say, from living with it.

There was really no need of the trans-Atlantic feat of Signor Marconi to convince us that he was doing a great work, but when we heard of that, we certainly felt that he had done far more than we ever expected he would do in so short a time. I well remember when a few weeks ago the announcement was made in the newspapers. I first heard of it through a reporter's call over the telephone, which was, " What do you think of Marconi? " I replied, " Why, what has he done? I haven't read the papers to-day." " Why, he claims that he has sent messages across the Atlantic." I answered, " If he says he has done that, he probably has done it." (Applause.) Signor Marconi's method of work has been such as to command the admiration of all engineers, and of all scientific men, because it has been scientific from the first, and at the same time he has never lost sight of the commercial aspect of the subject. The whole field of wireless telegraphy is one full of most interesting scientific problems, and were there not the slightest probability of a commercial outcome there would be a grand edifice of scientific work remaining. But, on the other hand, there is indeed the greatest promise of commercial results, and Marconi has even taken you into his confidence to only a certain degree here to-night. I have no doubt he would be able to say a great deal more of what he can promise in times to come if he wished to do so. He is not yet sure of some things that he knows pretty well will come to pass, but he is modest enough to stand back and say "I won't say anything about those now." He has given us in private a few suggestions of what he has been doing, and what he expects to do.

The man who succeeds in this world is one whose ardor is not damped by obstacles, one who makes obstacles stepping stones. In my philosophy of life, I find that there are two classes of people: Some meet an obstacle and say " I cannot get over that"; others say " I must get over that," and, having got over it, they open up a wide field of useful art or something of the kind; they make an advance; their ardor is not damped by obstacles in the way. The successful men are those who, instead of being set back by an obstacle, say " This is a stimulus to do better, to go farther, to progress to a degree which I at first did not think was possible."

The modern age, the age in which we live, is distinguished from the ages preceding by the quickness with which scientific work and discovery, however recondite they may be, however theoretical they may seem at the start, are soon put to practical use whenever they can be used. Instance, for example, the Roentgen ray, which was no sooner known as a scientific discovery than surgeons began using it. We also find that it is being used in the diagnosis of disease, such as tuberculosis of the lungs and in pneumonia. Further than that, these rays have another quality; they are used in actually killing bacteria, curing skin diseases, and even, to a certain extent, cancerous growths upon the skin. All these uses of the Roentgen rays have been discovered and developed within a very short time.

Hertz waves were discovered about fifteen years ago. They were simply a confirmation of the electro-magnetic theory of light as enunciated by Maxwell, oscillations taking place in a discharging circuit, or oscillations produced in any way in a circuit, and a radiation of energy from that circuit taking place in all directions in the form of Hertz waves in the ether. These were found and recognized, at varying distances away, by suitably attuned receivers. And upon this basis it is that Marconi has built. It was long ago pointed out by Henry that condensers, Leyden jars, in discharging produced oscillations. Clerk Maxwell dealt mathematically with the same problem. Hertz however, by experimental investigation proved the reality of these things which had been mathematically treated of before. Wireless telegraphy of to-day is built upon the foundation laid by Hertz.

We have in the electrical gamut all sorts and kinds of oscillations. The Roentgen ray may be said to top the scale with its thousands of millions of millions of oscillations per second. The ordinary luminous rays come further down in the scale; the violet topping the rate in the ordinary spectrum, down to the red, where we find the pitch much lower. Below that we find the invisible heat rays, and further down still the very wide range of pitch covered by the Hertz waves or oscillations, as they are termed, the same in their nature as light waves, but invisible, carrying energy and capable of being produced over a very wide range of what is called frequency. Marconi tells us that he has used a frequency of something like 800,000, or close to a million per second, which is, of course, many millions of times below the rate which would give us anything in the nature of light. In our ordinary alternating currents, however, we have only a very few waves per second. We have, then, the whole gamut from a few per second up to the most extreme possible rate which, perhaps, is capable of being generated by the atonic charges of matter in vibration.

I did not mean to take any great time to dwell upon these matters. It is certainly a surprise to me that the Anglo-American Company should attempt to hold back Marconi's experiments and to claim a monopoly not, as Signor Marconi says, of the earth and the air, but of the ether. What is this ether of which we talk so glibly? We do not know. It is apparently the substratum of everything. It is the thing of all things about which we probably know least, but which we know most certainly exists. It is something which we know must exist in space, but we know very little about its actual properties. And still the whole art of electrical engineering, the whole science of electricity, is built upon the interaction between the ether and ordinary matter, as we call it. In other words, we have in electrical work the science of the ether as affected by ordinary matter—the matter in ether. We cannot get along without matter. We cannot get along without ether. But whether matter itself is a form of ether—some modification which has been brought about in ether—is a question which the science of the future has to answer.

Wireless telegraphy will do away with many things which we have hitherto counted as necessities. We will have no dead cables or wires. The ether is always alive, communication always open. We will never need to think of open circuits in that medium. We will never need to think of a new investment in cables. When a man sends to you, at the end of a telegram wanting you to do something which you probably do not want to do particularly, " Wire answer," it may in the future take the form of " Please answer coherently." (Laughter and applause.)

THE TOASTMASTER.—Surely, ladies and gentlemen, this evening, if never before, the fact has been demonstrated that electricity has no nationality. Ralph Waldo Emerson, when visiting England a great many years ago, being impressed with the energy which he found on every hand in that little island, said that he regarded steam as half an Englishman. As we Americans look around us and contemplate the work which has been done in this country during the last forty or fifty years bearing the illustrious names of Joseph Henry, of Morse, of Alexander

Graham Bell, of Brush, of Edison, of Sprague, and many another of our fellow-members, why, we are half inclined to exclaim that electricity is altogether a Yankee. But even as that thought rises in our minds, there loom up the great classic shades of Faraday, the Englishman; Ampère, the Frenchman; Ohm, the German; and Jacobi, the Russian, to say nothing of great Italians—and we come back to the proposition which I have just enunciated, that electricity knows no nationality in its scope and in its achievement, as we have seen demonstrated and illustrated this evening.

And in calling upon the next and closing speaker of the evening, this fact is brought once more forcibly to our attention. It was once said by a great Slav, one of the finest metaphysicians and mathematicians the world has ever known, that, as for his countrymen, they had never been able to invent even a mouse-trap that anybody could sell.

It has fallen to the lot of one member of the Slavic race to be most successful in harnessing the great energies and forces of Niagara, and I would like to put it to the great telephone company in this country what it thinks of that mouse-trap theorem as applied to Dr. Michael I. Pupin. (Applause.) It is at least a singular and happy coincidence that on my right and on my left—both from the far eastern corner of Europe—are the two men who within the last year have most concentrated the scientific and electrical engineering attention of the world in the work which they have done in facilitating the communication of intelligence. I refer to Marconi and Pupin. (Applause.) Surely, they are assisting in that assimilation and blending of the nations which is now going on at a faster rate than ever before, and which perhaps was unhappily illustrated in a more barbaric fashion in the experience of the Chinese consul before he came to our city, being then stationed in Samoa with one clerk. It happened that a cannibalistic banquet intervened in which two chiefs participated, as the result of which the consul alone left the island. His next post of duty was in New York City, and in establishing his telephonic connection he requested Mr. Bethell to make his number "Two ate one John." (Prolonged laughter.)

Aside from the fact that Dr. Pupin is a distinguished member of the Slavic race, he has another call upon our gratitude, and that is as being a representative here to-night, with his fellow-professor, F. B. Crocker, of Columbia University, which upon its high hill in this city stands a bright beacon and center of illumination and culture and civilization and purity in political and social administration. More than that, we are indebted to one of its graduates and one of our fellow-members, who I am sorry not to see here to-night, Dr. Schuyler S. Wheeler, for one of the most munificent donations that a scientific body has ever received in this country from one of its members, in the purchase of the Latimer Clark Library and its gift to this INSTITUTE. (Applause). That gift was immediately secondéd by another gift from Mr. Andrew Carnegie, who, finding that somebody else besides himself had the library habit, immediately equalled Dr. Wheeler's gift, so that the library could be carried on and sustained.

And now, gentlemen, with that library, the equal of which does not exist in this world, we are looking around for a building, and when Signor Marconi has signalled across the Pacific ocean, we hope to entertain him in the tallest building the world has ever seen, because, gentlemen, you know that in a library building there is no limit to the number of stories. We have understood that possibly from the wealth which has been accumulated in telephonic circles, and even by our friend, Dr. Pupin, we may eventually hope to attain our fondest ambitions in that direction. I have now the greatest pleasure in introducing to you our distinguished fellow-member, Dr. Pupin.

DR. MICHAEL I. PUPIN:—Members of the INSTITUTE and guests. A few days ago our Committee on Papers was so kind as to invite me to be present here this evening as a guest and to make a few remarks on a subject with which the work of our distinguished guest of honor, Signor Marconi, has been identified. I have followed Signor Marconi's work with much respectful attention during the last six years. His experiments aroused my scientific interest and curiosity; his struggles excited my sympathy, and his success was always a source of the greatest gratification to me, as it is to all of you who are delighted in seeing true merit rewarded. (Applause.)

I shall, therefore, be very happy indeed if, by the few remarks which I have to offer this evening, I may in any way contribute to a clear understanding of the aims of our distinguished guest and of the means by which he hopes to accomplish his task.

One cannot very well discuss any topic connected with Signor Marconi's work without plunging headlong into the bottomless sea of electrical waves, and then he has to struggle hard to keep his head above the etheral fluid. He has, indeed, to be a very expert swimmer. He must be a physicist of ingenuity and rare skill; he must be a mathematician of exceptional training, and above all, he must be an engineer of sound judgment.

Now, I must say that I cannot lay a just claim to any one of these most exceptional qualities. You can see, therefore, that my position this evening is rather a difficult one. It is true that I do teach future electrical engineers in electro-mechanics, a subject which implies a fair knowledge of physics, electrical engineering and mathematics. I say, a fair knowledge only, and I mean that the amount of knowledge required is really a great deal less than people suppose. It would not be a wise policy for me to say this within hearing distance of our University, of course, because a professor's salary, small as it is, often depends on how easily he and his subject can be replaced (Laughter); but here in this distinguished assemblage, where I see the faces of some of the most distinguished engineers in the country, I must be frank if I am to expect leniency. It is true, also, that electro-mechanics has a great deal to do with electrical waves. Perhaps on that account I happened to take a particular interest in this field of work.

Now this subject of electrical waves has three sides: the purely mathematical side; the physical side; and, finally, the engineering side. It is on that account, perhaps, that those men who engage in the research of this particular subject are more or less pioneers, because the subject belongs to three different departments of general physics, without belonging to any one in particular. It is in the borderland, and that offers some advantages. If one working in the field of electrical waves happened to find something which after much argument his intimate friends admit to possess some novelty, then he goes to the American Mathematical Society and reads a paper on the mathematical side of his investigation; they say "Why, for a physicist he is a pretty good mathematician." Then he goes to the American Physical Society and gives an account of the physical side of his work, and they will generously admit that for an electrical engineer he is a pretty good physicist. Finally, he goes to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and gives them an account of the engineering side of his work and they will tell him that for a pure mathematician his engineering judgment is not at all bad. (Laughter.) In that way one gets on. It reminds me of a story which I heard Sir Robert Ball, the English astronomer, relate the other day in a lecture. He said that many years ago there was a famous professor at the University of Cambridge. He was famous, not because the people at Cambridge thought he was, but because the people of Continental Europe made him famous, and it happened in this way. He was a professor of astronomy and of geology. Whenever he called on his distinguished friends on the Continent he took with him two sets of visiting cards. On one set he was Professor of Geology and on the other set he was Professor of Astronomy. Whenever he called on a geologist he sent up the card on which his title was Professor of Astronomy and when he called on an astronomer he sent up his card with the title of Professor of Geology. In that way he became very famous as a man of broad learning. So it is with a man who works in electrical waves. He gains some fame, and he does not himself know how. As I said, because the subject of electrical waves is on the borderland, every man who works on the borderland is a pioneer, and the world, of course, admires the pioneer. It is, perhaps, on that account, also, that there is no particular class of men making the study of electrical waves a particular work of their own; that the subject of electrical waves is perhaps less understood than any other study in physics and electrical engineering. You have heard people say that Mr. Marconi's system is nothing more or less than Hertz's system; that there are Hertzian waves, and that they are transmitted through the ether. Another man will say that they are transmitted through the earth. Another will say thay are transmitted through the water. One man said to me the other day, " Why, anybody can do what Marconi did. One end of the Anglo-American cable was near Cornwall, and the other near Newfoundland, and Marconi sent his signal through the cable, and it is no wonder that the Anglo-American Company is kicking. He is using the cable for transmitting his signals. He is going to Cape Cod next. Another cable lands near there. He always goes wherever there is a cable terminal." (Laughter.)

Anybody who understands anything about the theory of electrical waves knows that to transmit oscillations of this enormous frequency through a cable would be a much more wonderful achievement than to transmit them through the ether. Now, I shall devote a few minutes, only, to some explanations—you see, teaching is my business and I must always explain, so if I am somewhat didactic you will understand that it has become a habit of mine; I cannot help it. I shall explain the difference, in as few words as I can, between the Hertzian waves, the telephonic or the Bell waves. and the Marconi waves. Several years ago I read an article written by that most distinguished mathematician, Oliver Heaviside. It was a criticism of another article written by another most distinguished physicist—the late Prof. Von Helmholtz, of the University of Berlin—and it dealt with the subject of the electromagnetic theory of light. Heaviside found fault with it, saying that it did not satisfy the conditions of a telegraphic circuit. Now, many of you will say: What in the name of common sense has a telegraphic circuit to do with the electro-magnetic theory of light? That is exactly what I said at that time. I did not understand it. Very often we do not understand Heaviside for the time being, but in about ten years or so his meaning suddenly dawns upon us. So one day last summer when it rained all day long, and it was impossible to go out and play golf or call upon one's idle friends, I was forced to stay home and pass my time in idle speculation; and, naturally enough, I speculated about electrical waves. It happened that a short time before that I spent a very pleasant evening with Signor Marconi under this very roof, and our conversation somehow or other drifted in the direction of electrical waves; some bits of this conversation still stuck in my brain, and the principal subject of my speculation on that day was concerning the conversation I had with our distinguished guest. I said to myself, now, here are Hertzian waves and Marconi waves and Prof. Bell's waves, and all other kinds of waves. What is the use of calling these waves by so many different names? I am perfectly sure, I said to myself, that Prof. Hertz, if he were alive would not care to hear people call any particular set of waves by his name, nor am I aware that Signor Marconi is anxious to label another set of waves as Marconi waves, nor that Prof. Bell claims all telephonic waves, nor that every telegraph or power transmission station working with alternating currents would care to label every one of its waves. It would not be just and it would not be practicable. I said to myself, there are no different breeds of waves; they are all one and the same thing. Well, said I to myself, if they are all one and the same thing, is there possibly any convenient method of classifying them? Well, there is. The difference between waves consists in the manner, in the combination of an apparatus, by which you produce them, and the purpose for which you wish to employ them.

Now, I said a little while ago, that the subject of electrical waves has a mathematical, a physical and an engineering side. Speaking from a purely mathematical and physical standpoint, there is no difference between electrical waves, absolutely none. But speaking from an engineering point of view, there is every difference between them. How absurd it is, then, to hear every now and then people say, "Why, years ago I stuck a wire here and I stuck a wire there and I actually transmitted signals across my back yard, using an open circuit; my work is just as good as Marconi's; there is no difference between us." Why, you might just as well say that there is no difference between the Brooklyn Bridge and the bridge which Julius Cæsar describes in his book "De Bello Gallico." There is every difference, the difference consisting chiefly in the construction of the apparatus which you employ. I also heard a man say, "Years ago I thought of transmitting wireless signals by the wobbling of the charge of the earth." Well, any one of us can think of schemes like that; any one of us who has had any experience in inventing can think of schemes like that as fast as you can write them down, for anybody knows you can transmit electrical waves to any distance, that is, mathematically and physically perhaps. But how about the engineering side of it? I said to this man, "Give me an engineering specification of your apparatus by means of which you intend to wobble the charge of the earth, and then I will believe you; not before."

Now this is what Signor Marconi has done. He has written out a specification for setting up apparatus and wobbling the charge of the earth and transmitting the signals between wires. (Applause). We have here, then, the idea and the engineering fact. The idea is all right as far as it goes, but without the engineering specification it amounts to nothing as far as the possibility of obtaining desirable results is concerned.

Well, now, what are the Marconi waves and the Marconi apparatus? In fact, I will take the first question back. I ask what is the Marconi apparatus, because if you know what the telephone waves are and the telegraph waves and the Hertzian waves, you know what the Marconi waves are. They are exactly the same thing. What we want to know is, what is the Marconi apparatus, and does it differ or does it not differ, from other apparatus, employed before, for the production of electrical waves? Now, on that rainy summer day when I sat speculating, I came to this conclusion: All apparatus for the production of electrical waves and the reception of electrical waves by the law of evolution or the law of continuity, may be deduced from two sets of telegraphic circuits. That is what Heaviside meant when he said that Helmholtz's theory did not satisfy the conditions of a telegraph circuit.

I shall now show you how we may take a telegraph circuit and by a continuous change evolve from it the Hertzian apparatus for the production of electrical waves. I do not think that any subject dealing with engineering can be properly presented un-

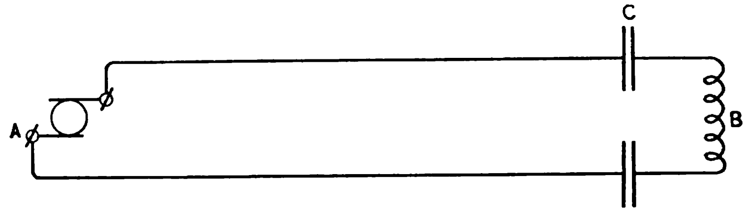


FIG. 1.

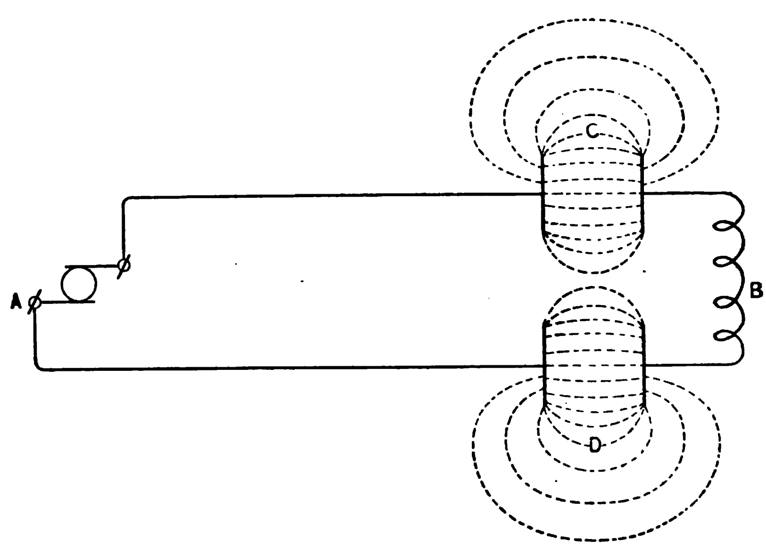


FIG. 2.

less you have either a blackboard or a few diagrams, and so I venture to offer you a real novelty, an after-dinner speech illustrated by diagrams. If, in spite of this effort on my part, you fail to understand my jokes, it will not be my fault. Here is diagram Fig. 1:

This may be called a typical telegraph circuit. A is the sending generator and B is the receiving apparatus; for a specific reason I have introduced two condensers, C and D. If the circuit is long, say a mile and the condensers are large, we can use a transmitting generator of low frequency. In the next place, let us increase the frequency by giving the generator a higher speed. Now we may diminish the size of our condensers. The size of the condensers may be diminished by putting the plates further apart as shown in Fig. 2. Here I want to call your attention to the fact that the electro-static lines of force begin to bulge out. In the first case shown in Fig. 1, the lines of electro-static force were practically all straight from plate to plate, because there was no stray external field. But in the second case there is, that is to say, the condenser begins to be more sympathetic

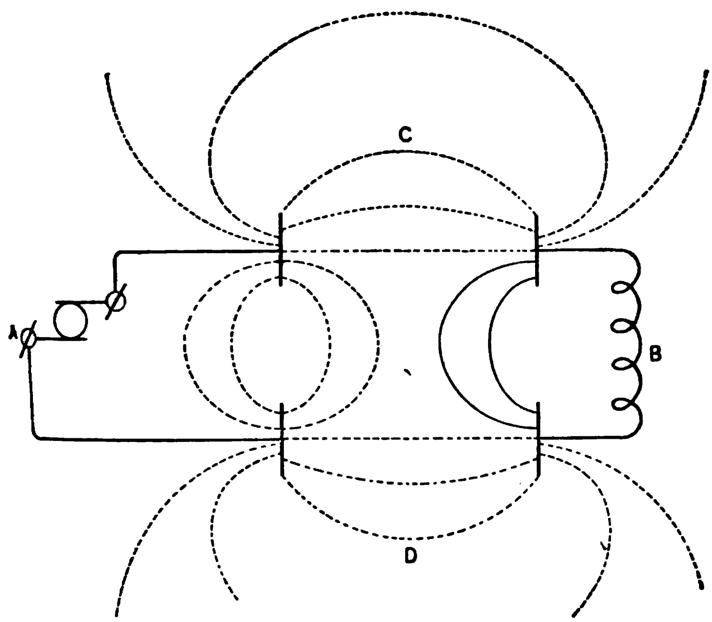


FIG. 3.

and to communicate with the rest of the world, throwing out its feelers in the shape of electro-static lines of force. Now, increase the frequency of the alternator still further and, of course, as everybody knows, we may still further diminish the capacity of our condensers, which we do by separating the plates C and D and placing them at a considerably longer distance apart, as shown in Fig. 3. The fact to which I wish to call your particular attention is that the electro-static field of force is bulging out still more; it throws out its feelers more and more and can affect bodies on the outside. We say that the condensers and therefore the total arrangement begins to have more and more radiating power. Radiation is simply the capacity of a system to communicate energy to other bodies outside of the system. You see, then, that as the frequency increases, the condenser plates may be taken further apart and the system begins to have larger

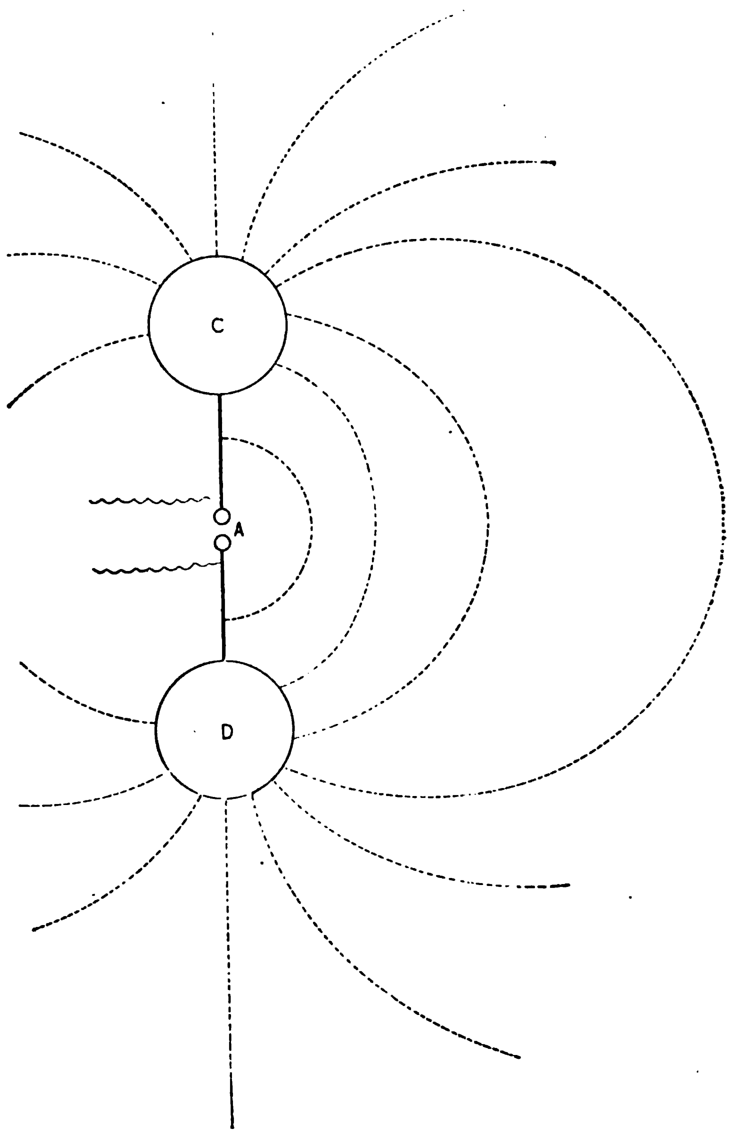


Fig. 4.

and larger capacity for radiating power, and to affect bodies outside of the electrical circuit under consideration.

Suppose, now, that we want to work at a still higher frequency, having in the last case reached a frequency of ten thousand periods per second. From this point on, sound engineering judgment tells us—and, mind you, I said that in dealing with electrical waves in their practical applications you have to be not only a mathematician and a physicist, but you must be also an engineer, that is to say, you must have sound practical judgment—from that point on, sound engineering judgment tells us: You have reached the limit of speed of the machine. The periphical speed is 6,000 feet per minute. Stop. You must use, now, something else. Our knowledge of physics tells us to use an artifice which Joseph Henry employed in 1842 and Feddersen again in 1858, and finally Hertz in 1887, with the brilliant success of which you all know. We use a spark gap. The condensers are now replaced by two balls, C and D, as indicated in Fig. 4. In place of the generator is the spark gap A. This is all that is left of our circuit. The receiving end of our circuit may be put anywhere. After every spark discharge at A we have rapid oscillations of any frequency that we choose to select. It is just like striking a bell; after each stroke we have a sonorous sounding of the bell. The bell becomes silent again after it has sent forth into all directions the energy communicated to it by the stroke. Observe here, now, the radiation of the lines of electric force: Here is a perfect type of a sympathetic circuit—a circuit which throws its feelers of electric force in every direction, ready to communicate energy to any other circuit or body at its own expense. This is a circuit of large radiating power. But for that very reason it gives off its energy at a rapid rate; it is not sonorous, but so lavish in its radiating power as to be almost aperiodic. It does not continue to vibrate, but during its very first vibration its entire energy is thrown upon the outside world.

Now this is the Hertzian oscillator. You can transmit wireless messages with that. But how far? If you transmit them a mile you are a fine manipulator. A gentleman told me the other day "At our University one of our young men years ago transmitted wireless messages over a mile, the same as Mr. Marconi." I said, "That is very nice for the young man, but how did he do it?" "He used a Hertzian oscillator," he replied. I said "That is a very different story. If he has transmitted a mile he has probably done a very good thing; but he could not do it any farther than that to-day, even if he had kept on trying from that day to this, whereas Mr. Marconi gets easily over a hundred miles." You see, this was an educated man and he understood the subject fairly well; nevertheless, he actually believed that his young man had done the same thing that Mr. Marconi is doing to-day, only his young man was too modest to announce his great feat to the world, and too unselfish to form a stock company.

This, then, is the apparatus, by means of which Hertz produced electrical waves. There was nothing very novel in that apparatus at the time when Hertz first employed it, and Hertz never claimed that there was anything novel in it, and if he had, there is no doubt that Prof. Lodge for one would have called him to order.

What, then, did he claim? All these oscillations can be and were predicted by Prof. Thomson, now Lord Kelvin, on the basis of the old theory, a theory of a hundred years ago, the theory which was completely worked out in the days of Ampère and Faraday. But there was one thing that could not be predicted by the old theory, and that is, that if you proceed from the oscillator in a certain direction you will get to a point where you get no induction, and then to a point where there is strong induction, and then again to another point where there is no induction, and thus he proved the existence of electrical waves in the ether. Hertz proved that electrical energy traveled from the oscillator with a finite velocity equal to the velocity of light. He did not claim the apparatus nor the waves. He claimed nothing except to have proved by experiment that electrical energy radiated from this apparatus with the velocity of light. That is the reason I said that if he were living to-day he would object that any waves should be called the Hertzian waves They are simply electrical waves.

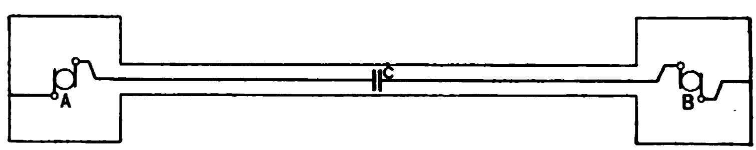


FIG. 5.

An engineer of sound judgment will tell you that from a mathematical and physical point of view you can transmit electrical waves to any distance, but he will also tell you that practically you cannot transmit them over more than a mile, if you employ the arrangement which Hertz employed.

This Hertzian arrangement was entirely different from the system known as the Marconi arrangement, and to prove it I shall now perform another transformation trick. I shall now evolve the Marconi system from the telegraph circuit of the second type. I told you that all apparatus for generating electric waves may be evolved from one of two types of telegraph circuit. The first type that I have just shown you is the land circuit; the second is the submarine type, the so-called cable. For this purpose I have borrowed a cable, not from the Anglo-American Company, but from the Commercial Cable Company. Here in Fig. 5 is a diagram of what may be called the second type of telegraph circuit, that is, a cable. Say this end at A is the transmitting apparatus at Cornwall, and this end at B is the receiving apparatus in Newfoundland. The line in the middle connecting A to B is the conducting core of the cable or the copper conductor. The terminal squares are the stations, and the tubular arrangement between them is the sheathing which protects the copper conductor. I have also put a condenser, C, in the middle. (Laughter.) I understand that is not the usual practice, but still it could be done. I violate no scientific principle in doing that, and I have introduced it for a definite purpose, which will be apparent presently. Now, to transmit signals over this cable we all know, and Mr. Marconi will not contradict us, that we have to transmit very slowly on account of certain limitations. Therefore, our alternator at A has to work at very low speed. Suppose, now, that we wanted to increase the speed of the transmitting alterna-

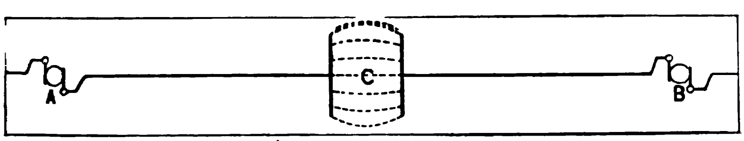


FIG. 6.

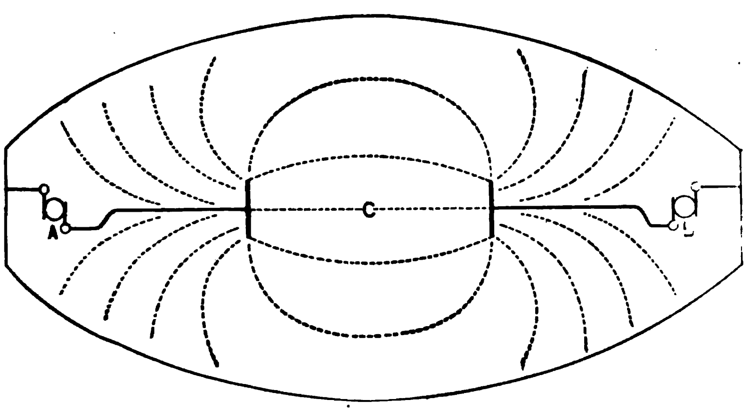


FIG. 7.

tor, thereby increasing the frequency of the alternating current which we employ, we would have to increase the cross-section of this sheathing so as to diminish the capacity; and we can also then diminish the capacity of the condenser C, without any loss or inconvenience, because the higher the frequency the smaller can be the capacity of condenser C.

Now, the second cable (Fig. 6), is a cable which has a higher speed. It is a cable of a larger cross-section of sheathing. I do not pretend that this is a practicable cable, but for the sake of the scientific demonstration it will do. The point to which I wish to call your attention is that, as the size of this condenser C is diminished, the lines of electro-static force, indicated by the dotted lines between the plates, begin to bulge out as if they were anxious to communicate their energy to the surrounding bodies.

Now, suppose we want to raise the speed of our transmitting apparatus, we would then have to increase the cross-section of our sheathing again, and we can then still further increase the distance between the condenser plates. Then we have this state of affairs shown in Fig. 7. The electro-static lines of force between the condenser plates bulge out very strongly. There is a very pronounced tendency on the part of the condenser to com-

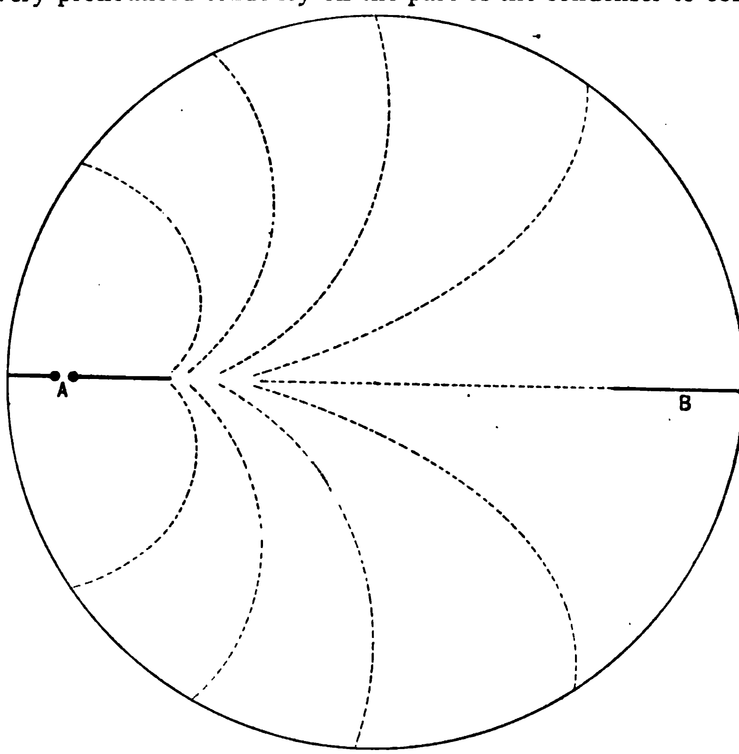


FIG. 8.

municate energy to the surrounding conducting bodies or to the ether.

With a cable like that we could use very high frequency. But suppose we wanted to use still higher frequency, then we would have to increase the sheathing very much, using the spark-gap, and then we would have this state of affairs shown in Fig. 8. Mind you, the sheathing now will be very thin indeed, and we can afford to have it as thin as we please because these high frequency currents are transmitted through a very thin layer near the surface of the conductor. So whether we have a thin or a thick conductor does not make any difference. The original sheathing will suffice to enclose as much space as we please.

There is nothing to prevent us from making this sphere as large as the earth.

Here is a system of wireless telegraphy that would be even better than Marconi's system. It would communicate most of its energy here from the transmitting apparatus A to the receiving apparatus at B. You see, the condenser and cable core have almost entirely disappeared; the capacity of the condenser C is replaced by the capacity between the terminal wires at A and B and the surrounding sheathing. But of course an arrangement like that, as big as the earth, would not do. So, although the scheme is a very nice one, mathematically, mind you, and

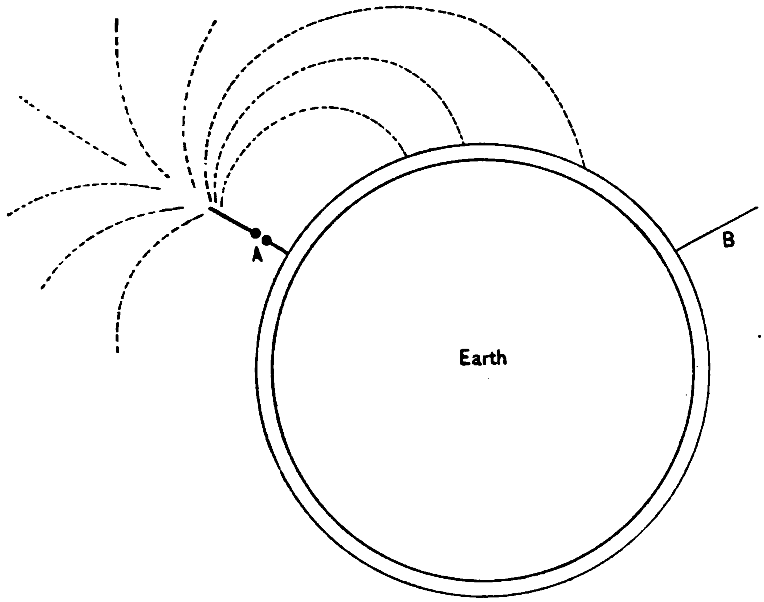


FIG. 9.

physically, it would not do from a purely engineering point of view. But it serves a very good purpose. It enables a mathematician to calculate in an exact and complete manner how the waves proceeding from A are going to be transmitted to B. You get a most beautiful result. It is a pity that the arrangement is not satisfactory from an engineering point of view.

But I said that a man dealing with electrical waves has to be not only a mathematician and engineer, but also a physicist. Now a physicist would say this: Why not make a cut here along a meridian of the spherical shell and then turn it inside out, and drop the earth into it. Then we would get this arrangement in Fig. 9. Here is now the sheathing all around the earth. Here is one wire at A, here is the other at B, and that is the Marconi system. (Applause.) It is more than that, because if he had this thin conductor all over the earth it would stop business and interfere with people. This thin conducting covering is a relic of barbarism, Sig. Marconi will undoubtedly say, reminding people of the cable from which we have just evolved his system. The physicist will tell you that it is unnecessary; the earth is a conductor, and therefore there is no necessity for the conducting sheathing; cut it out; run your transmitting wire, A, right into the earth and also the receiving wire, and you have the Marconi system. Here, then, in a didactic way, is, a complete representation of the Marconi system, and we have evolved it by gradual steps from the second type of the telegraph circuit. The Marconi system, therefore, satisfies Heaviside's condition, namely, that every electrical arrangement should satisfy the conditions of a telegraph circuit. The Marconi system must satisfy it because it has been evolved from it by gradual steps by the law of continuity. In fact, the form of transmission is the same as in the case of a telephone conductor, by conduction currents along the surface of the great conductor, which connects the transmitting wire to the receiving wire.

Now, it follows also that the Marconi system of wireless telegraphy, looked at from this view-point, is just as definite a problem, mathematically and physically, as the cable problem was in 1854, when Sir William Thomson, now Lord Kelvin, took it up, to calculate what can be done with it. I think that this system may be worked out mathematically with just as great accuracy as Lord Kelvin worked out the cable problem nearly 50 years ago. I am perfectly sure we can tell with close approximation what can be done with this system from a purely mathematical and physical point of view. What can be done with it, from a purely engineering and commercial point of view, is another question. The first objection which people will raise will be this: Here you have a common conductor. Anybody can stick a transmitting wire there and a receiving wire here and interfere with you. If you could put signs all over the earth and tell people to keep off the earth, then it would be all right, but you cannot do that. We are not all like the Anglo-American Company, claiming the earth and the sea and the ether. We have to let other people enjoy some rights and privileges. Now Sig. Marconi tells us that by the system of electric resonance and syntony he can overcome this difficulty. If he says so, I am inclined to believe him, if for no other reason. But in scientific work we never believe anything until we see a demonstration of it. I believe that Sig. Marconi has transmitted the famous three dots across the Atlantic, but I must say that I believe him because I know him personally. If I did not know him personally, I would not believe him, because the proof which Signor Marconi has furnished is not sufficiently strong from a purely scientific point of view; but knowing him personally as I do, I believe his statement. Well, what of it? Suppose he has transmitted trans-Atlantic signals. Suppose that the wireless system of telegraphy enables us to transmit signals across the Atlantic in a satisfactory way, what of it? Is that going to affect the condition of the present cable companies? It may at first, perhaps, if the Marconi system proves to be just as good a system and even a better one than the present cable systems. But it will affect them in the same way that electric lighting affected the gas companies. Gas stock went down at first. To-day it is way up. How did the telephone affect telegraphy? Why, telegraphy stands higher to-day than it did in 1876. Do you suppose the perfection of bicycles and automobiles has affected the price of horses? Why, last spring the prices of horses were higher than at any other time in the history of this country. I myself sold a horse last spring to a dealer for more than I paid for it several years ago. (Laughter.) So that I, for my part, if I had a lot of stock in a cable company, which unfortunately I have not, I would stick to it. I think that every success that Marconi may accomplish will help the cable business, instead of doing the contrary. I think that whatever may happen, whether Signor Marconi succeeds in giving us a better system of transmitting intelligence across the Atlantic or not, of one thing we may be certain, and that is, that we must judge him to-night by what he has done. He has done great things. He has supplied us with a method of communicating between moving ships, between ships and lighthouses and between places between which there was no communication before. That is a grand thing, and if Signor Marconi does not accomplish another thing, he has done enough for any man to be satisfied with. But I think it will be a grand thing if he should succeed in perfecting a system of transmitting intelligence across the Atlantic and the Pacific with the same exactness, facility and promptitude with which the present cable companies transmit messages. It would be a great thing because we would then have a competitor, and there is nothing so powerful in stimulating progress as competition. The trouble with the cable companies, if there is any, is that they have had no serious competitor. There was no progress, in a certain sense, but I should rather say that there was progress, only I think there might have been a great deal more progress, if there had been more competition; if two or three or four different systems had been competing against each other. Let Sig. Marconi perfect his trans-Atlantic system. I wish him success from the bottom of my heart, because I am sure that if he does succeed there will be a cable transmission system in less than ten years that will astonish the world. I am sure, therefore, that every one of us, the cable engineers included, wish Signor Marconi a signal success. (Applause.)

At the conclusion of Dr. Pupin's remarks the toastmaster invited the guests and members to remain for a few moments after the banquet, if they desired, so they might have the opportunity of being presented to Signor Marconi. The privilege was generally accepted and the guest of the evening was the recipient of hearty congratulations from the members present.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, Jan. 24. 1902.

The meeting was called to order by President Steinmetz at 8.15 P.M.

SECRETARY POPE:—At the meeting of the Board of Directors this afternoon the following Associates were elected:

NAME.	ADDRESS.	ENDORSED BY
ADAMS, WILLIS LONGFELLOW,	General Manager, Adams Construction Co., 726 Buffalo Ave., Niagara Falls., N.Y.	W. H. Ripley. C. Van Deventer. J. F. Kelly.
ARNOLD, WARD S.	Electrical Engineer, Railway Department General Electric Co., Monadnock Building; residence 384 E. 40th St., Chicago, Ill.	James Lyman. H. E .Chubbuck. G. W. Knox.
BINDEMANN, HARRY OTTO FERDINAND,	Electrical Engineer, Union Electricitats Gesellschaft, 43 Dorotheen Str., Berlin, Germany.	H. M. Hobart. W. S. Hulse. R. W. Pope.
BLACKWELL, HOWARD LANE,	Assistant in Physics, Harvard University, 13 Little's Block, Cambridge, Mass., residence East Orange N. J.	C. A. Adams, Jr. S. S. Wheeler. G. S. Dunn.
CABOT, SEWELL,	Manager, Back Bay Exchange, New England Tel. and Tel. Co., 208 Newbury St., Boston; residence, High Street, Brookline, Mass.	H. W. Wilder. F. L. Gilman. G. F. Atwood.
CALDWELL, EUGENE WILSON,	Director, Edward N. Gibbs Laboratory, University and Bellevue Hospital Medical College, 315 Fifth Ave.; residence. 20 E. 31st St., New York City.	W. D. Weaver. C. T. Child. J. J. Carty.

Dixon, James, Electrical Engineer, Gray National Telautograph Co., Room 142, 80 Broadway, New York City; residence, 241 Franklin Place, Flushing, N. Y.	E. F. Peck. Geo. F. Sever. F. B. Crocker.
Ehret, Cornelius Dalzell, Examiner, U. S. Patent Office, Room 9, Washington, D. C.	G. K. Woodworth E. E. Clement. C. L. Sturtevant.
Fleming, Richard, Designing Engineer, General Electric Co., Lynn; residence, Swampscott, Mass.	C. P. Steinmetz. W. C. Fish. A. L. Rohrer.
Graham, William P., Professor of Electrical Engineering, Syracuse University, 504 University Place, Syracuse, N. Y.	E. L. Nichols. W. B. Hodge. J. G. Biddle.
Jones, Fred Atwood, Railway Engineering Department, General Electric Co., Schenectady, N. Y.	H. E. Molé. H. J. Ryan. W. I. Slichter.
Kier, Samuel Martin, Electrical Engineering Dept., Westinghouse E. & M. Co.; residence, 5904 Elgin Ave., Pittsburg, Pa.	C. F. Scott. R. A. Fessenden. N. W. Storer.
Lillibridge, Ray D., Stanley Electric Mfg. Co., 20 Broad St., New York City; residence, 146 Quincy St., Brooklyn, N. Y.	T. C. Martin. W. D. Weaver. F. A. C. Perrine.
Morgan, Carl Leon, Assistant to Purchasing Agent, Edison Electric Illuminating Co., 3 Head Place; residence, 25 St. Cecilia St., Boston, Mass.	C. L. Edgar. C. H. Harris. Joseph Sachs.
Parsons, Isaac Dayton, Assistant in Electrical Engineering Dept., Columbia University; residence, 314 W. 23d St., New York City.	F. B. Crocker. G. F. Sever. F. Townsend.
Randolph, Mervyn Paul, District Office Manager, Westinghouse E. & M. Co., 314 Occidental Ave., Seattle, Wash.	C. F. Scott. R. S. Masson. E. M. Tingley.
Ryan, Walter D'Arcy, Engineer, General Electric Co., Lynn, Mass.	E. Thomson. W. C. Fish. C. P. Steinmetz.
Seabrook, Henry Hamilton, Sales Engineer, Westinghouse E. & M. Co.; residence, 822 Connecticut Ave., Washington, D. C.	C. F. Scott. P. H. Lange. W. K. Dunlap.
Sullivan, William Van Amberg, Jr., 2d Assistant Engineer, U. S. S. Rush, Sitka, Alaska.	A. G. Davis. G. K. Woodworth. T. W. Ross.
Terry, Albert Slocomb, Treas. and Manager, The Sunbeam Incandescent Lamp Co., 463 West St.; residence, 59 Morningside Ave., New York City.	G. F. Atwood. G. A. Hamilton. P. G. Burton.
Touret, Maxime Eugene Jean, Consulting Electrical Engineer, 7 Rue Meyerbeer, Paris, France.	Chas. Le Blanc. R. W. Pope. W. J. Hammer.

VON RECKLINGHAUSEN, MAX,	With Mr. George Westinghouse, 510 West 23d St.; residence, 11 East 24th St., New York City.	C. A. Terry. G. H. Stockbridge A. J. Wurts.
WARREN, HENRY ELLIS,	Assistant Engineer, The Lombard-Governor Co., Newton Centre, Mass.	A. V. Garratt. Chas. Cross. R. W. Pope.
WHITESIDE, WALTER HUNTER,	Manager, Westinghouse E. & M. Co., 1317 F. St.; residence, 1405 W. St., Washington, D. C.	C. F. Scott. L. A. Osborne. C. E. Skinner.
YAMAZAKI, SHIRO,	Student of Electrical Engineering, Cornell University, 408 University, Ave., Ithaca, N. Y.; residence, Tokyo, Japan.	E. L. Nichols. H. J. Ryan. A. L. Hoxie.

Total, 25.

PRESIDENT STEINMETZ.—Gentlemen: I have to announce that the next meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS will be a special meeting, to be held on the evening of Feb. 14 at 8 P.M., at Columbia University. At this meeting a paper will be read by Mr. Percy Thomas on static strains in high tension circuits and the protection of apparatus. This paper will be illustrated by a number of very interesting experiments and therefore the lecture will be given at Columbia University. Ladies are invited.

The topic for to-night's meeting is the electric railway. While electric railroading is perhaps the most important branch of electrical engineering, at least as regards commerical importance, considering the amount of capital invested therein, nevertheless it is a remarkable fact that while most other branches of electrical engineering had been developed to a very high degree of perfection, even a few years ago theoretical investigation of electric railroading was still conspicuous by its almost entire absence.

All the work was done by some kind of empirical experimenting, that is, some motor was fitted up with some gearing or some sort of railway car, and then run, and if the motor burned out frequently it was replaced by a larger motor, and if it did not burn out, a trailer was put on the car, and perhaps a second trailer. until the increase of the expense account in burn-outs of the motors balanced the increased carrying capacity of the train.

Perhaps the first theoretical investigations of electric railway problems are contained in a number of papers presented to the INSTITUTE on train acceleration by one of my former assistants, Mr. A. H. Armstrong. They led to the proposition of the typical motor cycles, the type curve in Fig. 1 of Dr. Hutchinson's paper. That is a curve with time as abscissa and velocity as ordinate, consisting of acceleration, coasting and retardation or braking.

One of the most interesting results brought out by this investigation was the enormous importance, in its bearing on the motor capacity, of the number of stops and the frequency of stops. It followed that by increasing the number of stops per car mile, with the same schedule speed, the motor capacity had to be increased very greatly or else with the same motor capacity, the same number of stops rapidly reduced the permissible schedule speed. Some apparently paradoxical results were arrived at also, as for instance, the greater the power input into the motor in starting, the less is the total energy required to carry the railroad car at a given time over a given distance: and the less the maximum speed attained during the run, the greater is the amount of energy required to carry the car over a given distance in a given time.

These results at first were based on the type curve on Fig. 1 of Dr. Hutchinson's paper. By considering the motor curve, that is, the acceleration of the railway motor after the rheostat has been cut out, due to the decreased magnetization caused by a decrease of current, and corresponding decrease of motor torque, those results derived were and are modified in a more or less essential degree. From our present point of view, with our present knowledge, all of these results are really self-evident—as self-evident as anything is as soon as you know it.

The problem is to carry a given weight in a given time over a given distance. To do that the motor has to overcome the mechanical friction, which is, more or less approximately equal to train weight multiplied by coefficient of friction multiplied by distance. It is fairly independent of the character of motor control and also of the motor speed, within certain limits. This, then, is the work which is absolutely required for the carrying of the car over the track and therefore may be considered as the useful motor work. In addition thereto the motor has to give also the mechanical work which in stopping is consumed and annihilated by the brakes; that is, the mechanical output of the motor is greater than the useful work by the amount of energy consumed by the brakes, and the ratio of useful work, that is, energy consumed by train friction to total mechanical work of motor, that is, train friction plus energy consumed by the brakes, is what may be called the mechanical efficiency of the motor cycle.

Now, we immediately distinguish two different types of railway work here. One of them is the long-distance run, with very few stops, in which the energy consumed by the brakes in stopping is insignificant compared with the mechanical output of the motor. The mechanical efficiency is practically unity (except when descending heavy grades on the brakes), and therefore the rate of acceleration, retardation, etc., is immaterial. The other is when the railway motor is operated with frequent stops and short distances, as in city and rapid transit work, in which the energy consumed by the brakes is a considerable part of the mechanical output of the motor. There the mechanical efficiency has to be considered.

Now, it is obvious that the maximum mechanical efficiency is reached where the amount of energy consumed by the brakes in stopping is a minimum; that is, when the brakes are applied at the minimum possible speed, since the energy consumed by the brakes is proportional to the square of the velocity at the moment of applying them. Under given conditions of distance and schedule speed, it follows herefrom immediately that for mechanical efficiency the most efficient operation of the motor is to accelerate and to retard as quickly as possible, at as high a rate as possible, and to coast in between. The total efficiency of the motor cycle, however, as the ratio of useful work to total electrical input in the motor, is the product of the mechanical efficiency, as discussed above, and the electrical efficiency of the motor, that is the ratio of the mechanical output of the motor to the electrical input.

The operation of the motor during acceleration consists of acceleration on the rheostat and acceleration on the motor curve—the acceleration on the motor curve being at very high efficiency. In the acceleration on the rheostat the mean efficiency necessarily must be below 50%, because, assuming a constant acceleration, the input into the motor is constant, independent of the speed, while the speed varies from zero to a maximum, that is, to the speed where the rheostat is completely cut out. The average speed is half of this speed, while the energy input corresponds to the maximum speed, so that the actual efficiency during the period of acceleration on the rheostat is approximately the efficiency of the moment when the rheostat is completely cut out, divided by two. This is not exact, because at lower speed the core loss is less, but it follows therefrom that the maximum electrical efficiency requires to have as long a range of acceleration on the motor curve and as short a range on the rheostat as possible. During acceleration on the motor curve, the current decreases, that is, the acceleration decreases, and, consequently becomes less than the maximum acceleration assumed, with reference to the maximum discomfort the passengers will stand, etc. The greater the range of acceleration on the motor curve, the higher is the electrical efficiency, but the lower is the mean acceleration, that is, the lower the mechanical efficiency; and you see herefrom that the two components of total efficiency, electrical and mechanical efficiency, are antagonistic, the mechanical efficiency requiring maximum rate of acceleration, the electrical efficiency requiring maximum range of acceleration on the motor curve, that is, lesser mean acceleration. The problem of the designing of the motor cycle in an efficient electric motor control consists then in combining the two efficiencies and the rate of acceleration, etc., in such a manner as to get the maximum resultant efficiency.

After these introductory remarks I call upon Dr. Cary T. Hutchinson to present his paper.

Dr. Cary T. Hutchinson then presented his paper entitled "The Relation of Energy and Motor Capacity to Schedule Speed in the Moving of Trains by Electricity"

A paper presented at the 160th Meeting of the American Institute of Electrical Engineers, New York, January 24, 1902, President Steinmetz in the Chair.

THE RELATION OF ENERGY AND MOTOR CAPACITY TO SCHEDULE SPEED IN THE MOVING OF TRAINS BY ELECTRICITY.

BY CARY T. HUTCHINSON, PH.D.

The determination of the energy and power necessary to make a certain schedule speed from start to start under various conditions of initial accelerations, braking and use of the " motor curve " is a matter of much practical importance. A number of articles discussing special cases have been published. This paper gives a general solution of the question involved in the movement of a body from rest to rest with velocity varying as shown in Figs. 1 and 2—these two figures illustrating the practical problem of train acceleration. The solution here given covers all cases that can arise in ordinary practice of train movement. It affords a ready means of determining the energy, the power and the losses for any schedule speed, over a course of any length with any initial acceleration, tractive resistance or braking effort, and with any desired use of the " motor curve."

The solution is partly analytical and partly graphical; it may be divided into three stages: (1) The determination of the elements of Fig. 1 to give any schedule speed; this velocity-time (v-t) curve I shall refer to as the " type curve." (2) The determination of a general tramway motor curve sheet and the deduction from this curve sheet of several dependent curves; and (3) The application of the general motor curves to the type curve of Fig. 1 to obtain a general solution of the (v-t) curves of Fig. 2. Each case of Fig. 2 is reduced to a case of Fig. 1 by applying a correction to Fig. 2, represented by the area M A N, by which it is reduced to a corresponding case of Fig. 1.

Throughout the following units are used:

Velocity, in miles per hour (mph).
Acceleration, in miles per hour per second (mph./sec.
Distance, in feet (L).
Time, in seconds (t).
Weight, in pounds (w).
Power, in kilowatts (kw).
Energy, in watt-hours (wh).
These units are related as follows:
Miles per hour (mph.) = 0.682 × feet per second.

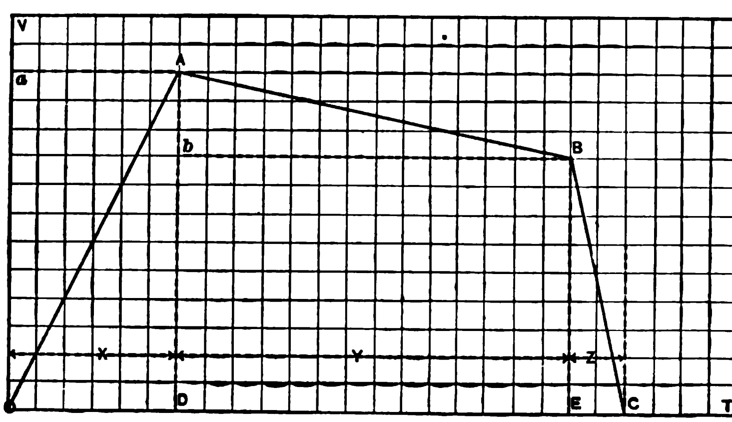


FIG. 1.

Miles per hour per second (mph./sec.) = 0.682 × feet per second per second.

Kilowatts (kw.) $= 9.1 \times 10^{-5} \times$ w (mph./sec.) (mph.)

Watt-hours (wh.) $= 1.25 \times 10^{-5} \times$ w (mph.)^2

And, therefore,

Kilowatts per ton (kw./ton) $= 0.182 \times$ (mph./sec.) (mph.)

Watt-hours per ton (wh./ton) $= 2.5 \times 10^{-2} \times$ (mph.)^2

In this system "*g*" the acceleration of gravity is 22; the ton is uniformly 2,000 lbs.

Referring to Fig. 1, suppose a train to move at constant acceleration from rest to velocity D A in time O D, then with constant retardation to velocity E B in time D E, and finally with constant retardation from B to C in time E C; the distances travelled in the time O D, D E and E C are represented by the areas O A D, D A B E and E D C, respectively, the acceleration by the inclination of the lines to the horizontal.

Let

a = Acceleration along O A = D A/O D.

b = Retardation along A B = A b/E D

c = Retardation along B C = B E/E C.

x = Time for O A = O D

y = Time for A B = D E

z = Time for B C = E C

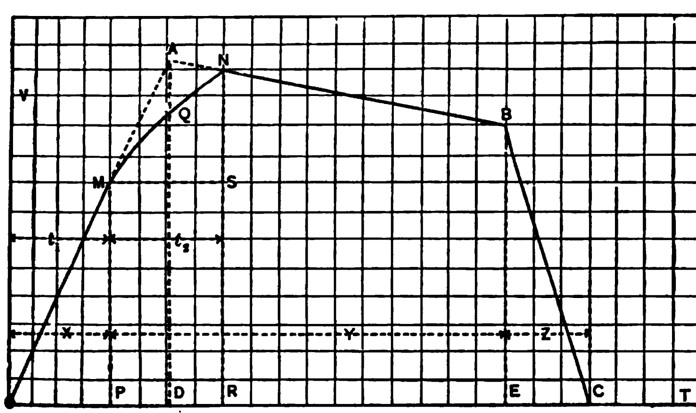


FIG. 2.

s_1 = Distance for O A = Area O A D

s_2 = Distance for A B = Area D A B B

s_3 = Distance for B C = Area E B C

T = Total time = O C

L = Total distance = Area O A B C

V = Average velocity = .682 L/T

Then these three equations hold:

Velocities: $a\,x - b\,y - c\,z = 0$ (1)

Times: $x + y + z = T$ (2)

Distances: $a\,x^2 - b\,y^2 + c\,z^2 + 2\,a\,x\,y = 2 \times .682\,L$ (3)

The work of solving these equations is tedious; I shall give only the results and in a simplified form:

Put

$$A = V/T = .682\,L/T^2 = 1.47\,V^2/L \tag{4}$$

$$2\,A_0 = a\,c/\,(a + c) \tag{5}$$

$$2\,M = (a+b)\,(a+c)\,(c-b)$$

$$K_1 = (c-b)/M^{1/3}$$

$$K_2 = (a + c)/M^{1/3}$$

$$K_3 = (a + b)/M^{1/3}$$

Where

$$K_1 + K_2 + K_3 = 0$$

Then will

$$x/T = 2\,A_0/a - K_1\,(A_0 - A)^{1/3} \tag{6}$$

$$y/T = \qquad K_2\,(A_0 - A)^{1/3} \tag{7}$$

$$z/T = 2\,A_0/c - K_3\,(A_0 - A)^{1/3} \tag{8}$$

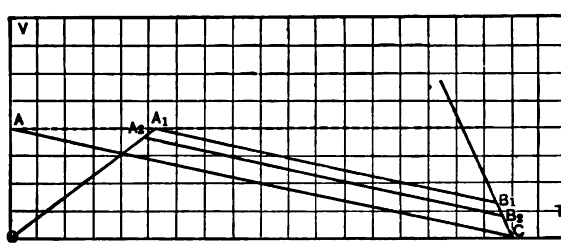


Fig. 3.

And

$$a\,x/T = 2\,A_0 - \; a\,K_1\,(A_0 - A)^{1/3} \tag{9}$$

$$b\,y/T = \qquad b\,K_2\,(A_0 - A)^{1/3} \tag{10}$$

$$c\,z/T = 2\,A_0 - c\,K_3\,(A_0 - A)^{1/3} \tag{11}$$

These three equations are the general solution of the problem in kinematics illustrated in Fig. 1; that is, the motion of a particle from rest to rest, with three different accelerations. The only term in the equations containing the average velocity or the length is A; all the other terms are functions of the three accelerations. This quantity A then determines completely the schedule. All schedules having the same value of A will be accomplished by the same accelerations in the same proportional times; that is, the same fraction of the total time will be occupied in the three phases of the movement. This quantity is then the independent variable and is of utmost importance in this discussion; it deserves a specific name, and for want of a better I shall call it the "THROUGH ACCELERATION," and denote it by A. All schedules with the same "through acceleration" but with different V and T, are represented by similar figures—the scale only being different.

These equations show that the maximum through acceleration for given values of (a), (b) and (c) is equal to A_0, and that this will occur when $y = 0$; that is, when there is no retardation along A B, or, in electric parlance, "no coasting."

Three special conditions of importance are readily determined:

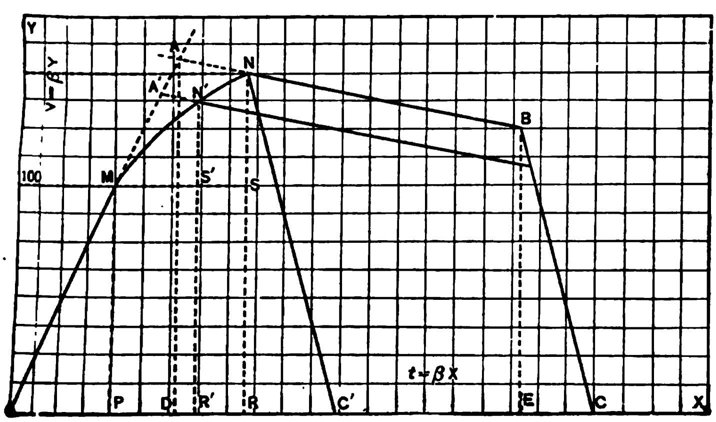


FIG. 4.

(1) Infinite acceleration, $a = \infty$

$$x/T = 0$$

$$y/T = \left(\frac{c - 2A}{c - b}\right)^{1/2} \tag{12}$$

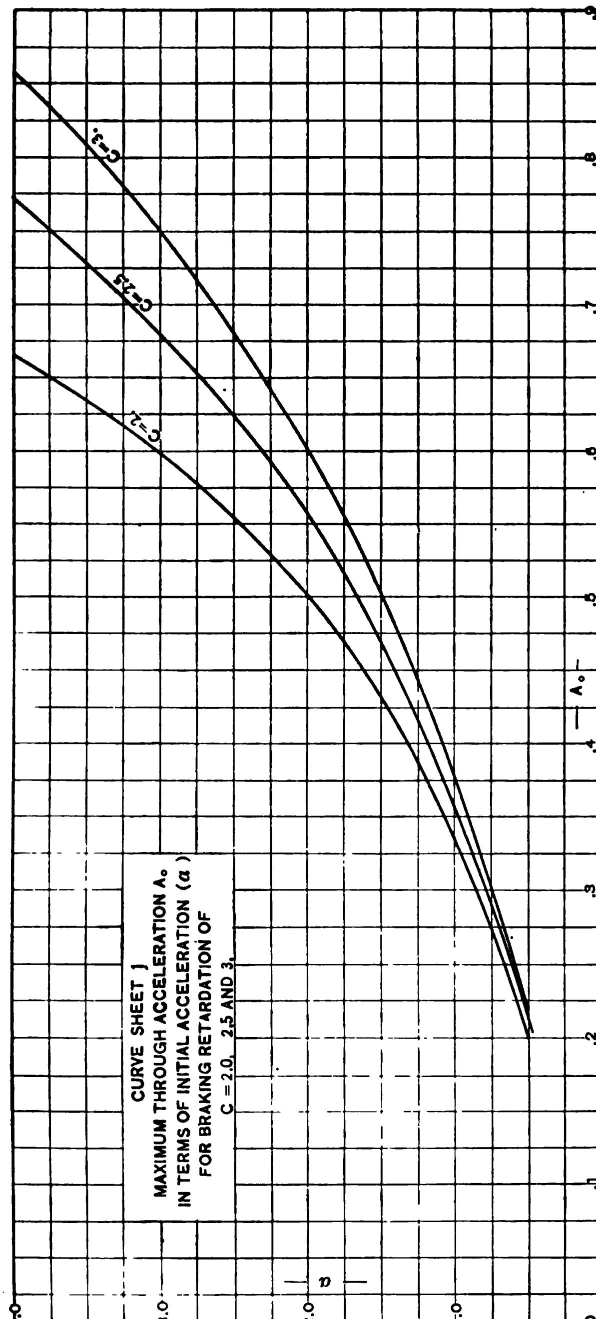
$$z/T = 1 - \left(\frac{c - 2A}{c - b}\right)^{1/2} \tag{13}$$

and

$$a\,x/T = c - (c - b)^{1/2}\,(c - 2A)^{1/2} \tag{14}$$

(2) No coasting, $y = 0$

$$A_0 = A = a\,c/2\,(a + c) \tag{15}$$


CURVE SHEET 1
MAXIMUM THROUGH ACCELERATION A₀
IN TERMS OF INITIAL ACCELERATION (a)
FOR BRAKING RETARDATION OF
C = 2.0, 2.5 AND 3.
C=3.
C=2.5
C=2.
A₀
a
4.0
3.0
2.0
1.0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9

(3) No braking, $z = 0$

$$a\,b/2\,(a+b) = A$$

$$x/T = b/\,(a+b) \tag{16}$$

Equation (15) determines the maximum through acceleration, and equation (16) the minimum through acceleration; all possible values lie between these two.

Equation (14) gives the maximum velocity for infinite initial acceleration; this is the least maximum velocity for any value of A greater than $b/2$. For values of A less than $b/2$ the maximum velocity for infinite acceleration is the greatest possible maximum. This seems abnormal, but that it is correct can be seen readily from Fig. 3, where O A C shows the curve for $A = b/2$ and $a = \infty$. Since A is represented by the area of the triangle O A C, it is clear that for an acceleration O A_2 A_1 the area O A_1 B_1 C is greater than O A C, and that at some point A_2 the area O A_2 B_2 C will be equal to O A C. That is, when the schedule is slow, the maximum velocity increases with the initial acceleration.

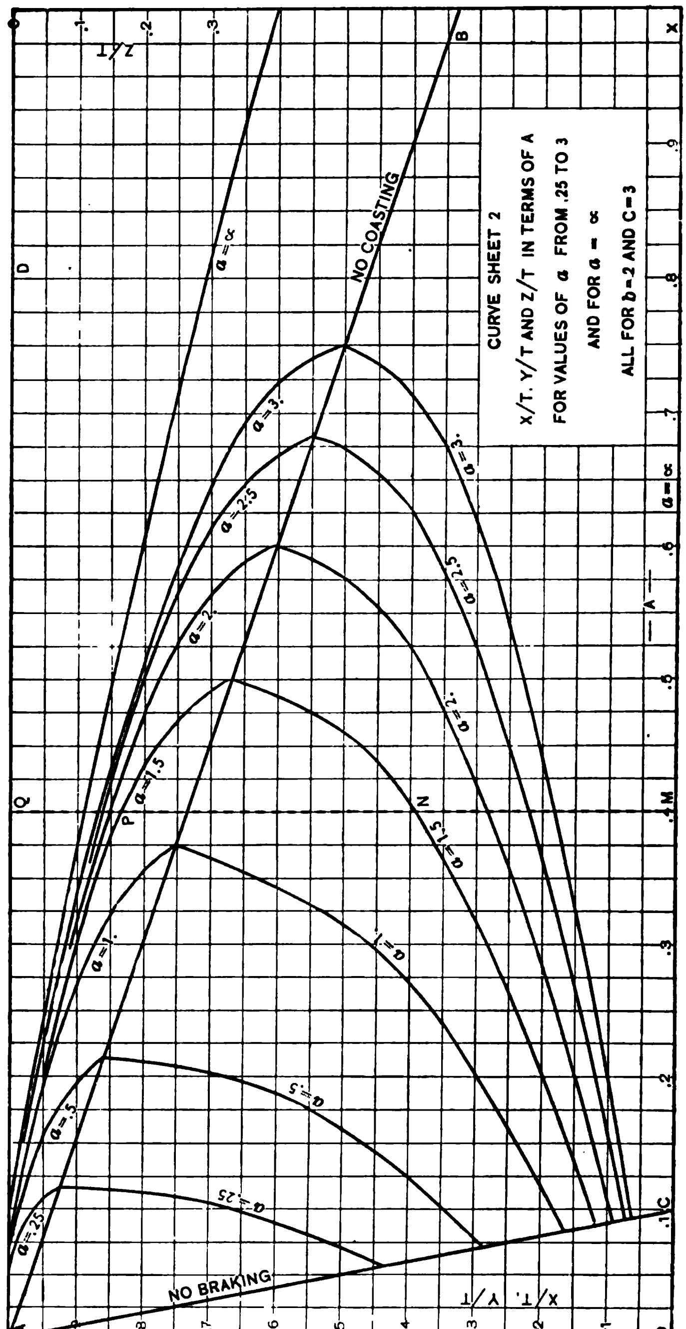
The relations of these quantities are best shown graphically; they are plotted in various ways on the curve sheets described.

Curve sheet 1 is plotted from equation (15), and shows A_0 in terms of (a) for $b = .2$, and for $c = 2$, 2.5 and 3. These are the maximum values of the through acceleration A in terms of (a) for the several values of (c). They show the influence of (c), the retardation after braking, on A_0.

Curve sheet 2 is plotted from equations (6), (7) and (8), and gives the values of x/T, y/T and z/T in terms of A for different values of (a) varying from .25 to 3.0, and for $a = \infty$; for $b = .2$, and $c = 3$.

The values of x/T are the intercepts between the X axis and the branch of the a curve lying below the line A B; the values of y/T are included between the two branches of the a curve, and of z/T are included between the line A D and the upper branch of the a = curve.

For instance, for $A = .4$, $a = 1.5$, $x/T =$ M N, $y/T =$ N P, $z/T =$ P Q. The line $a = \infty$ is the axis of X; the line A B is the locus of $y = 0$ or of "no coasting," and the intersection of the a-curves with this gives the maximum through acceleration for that value of (a). The line A C is the line of no braking, and its intersection with the a-curves gives the minimum values of A


CURVE SHEET 2
X/T, Y/T AND Z/T IN TERMS OF A
FOR VALUES OF a FROM .25 TO 3
AND FOR a = ∞
ALL FOR b = 2 AND C = 3
NO COASTING
NO BRAKING
X/T, Y/T
Z/T

These curves give all possible values of A, and enable Fig. 1 for any particular case to be drawn at once.

Curve sheet 3 is plotted from equation (9), and gives $a\,x/T$ in terms of A for different values of (a), and for $b = .2$, $c = 3$. These curves show at a glance the variation of maximum velocity with different initial acceleration, and the crossing of the a-curves.

Curve sheet 4 shows $a\,x/T$ in terms of A for $b = .2$ and for $c = 2.0$. It illustrates the influence of the braking effort on the maximum velocities.

These curve sheets give a complete determination of the kinematics of the problem. There remains the determination of energy and power—the kinetics. I limit the discussion to the case in which power is applied along O A (Fig. 1) only, and the car is allowed to "coast" with gradually diminishing velocity due to the constant retardation (b) from A to B, where a braking force producing a retardation $(c - b)$ is applied, making a total retardation equal to (c).

The assumption of (b) constant is necessary to a simple discussion; if it is not so, an average value may be used—considerable variations in the value of (b) make little difference. I use throughout $b = .2$ M.P.H./sec., equal to a force 18.2 lbs. per ton; (b) represents the total tractive resistance on a level at uniform speed. and with electric motors, includes motor friction.

The force exerted along O A (Fig. 1) is

$$f = \frac{w}{g}\,(a + b), \text{ lbs.}$$

and the total energy input at the car axle, per ton, up to the point A is

$$2.50 \times 10^{-2}\,(1 + b/a)\,\overline{a\,x^2}, \text{ wh} \tag{17}$$

Of this energy

$$2.5 \times 10^{-2} \times \overline{a\ x^2}, \text{ wh}$$

is represented by the kinetic energy at point A, and

$$2.5 \times 10^{-2}\,\overline{a\,x^2} \times b\,/a, \text{ wh}$$

is the work done in overcoming tractive resistances up to point A.

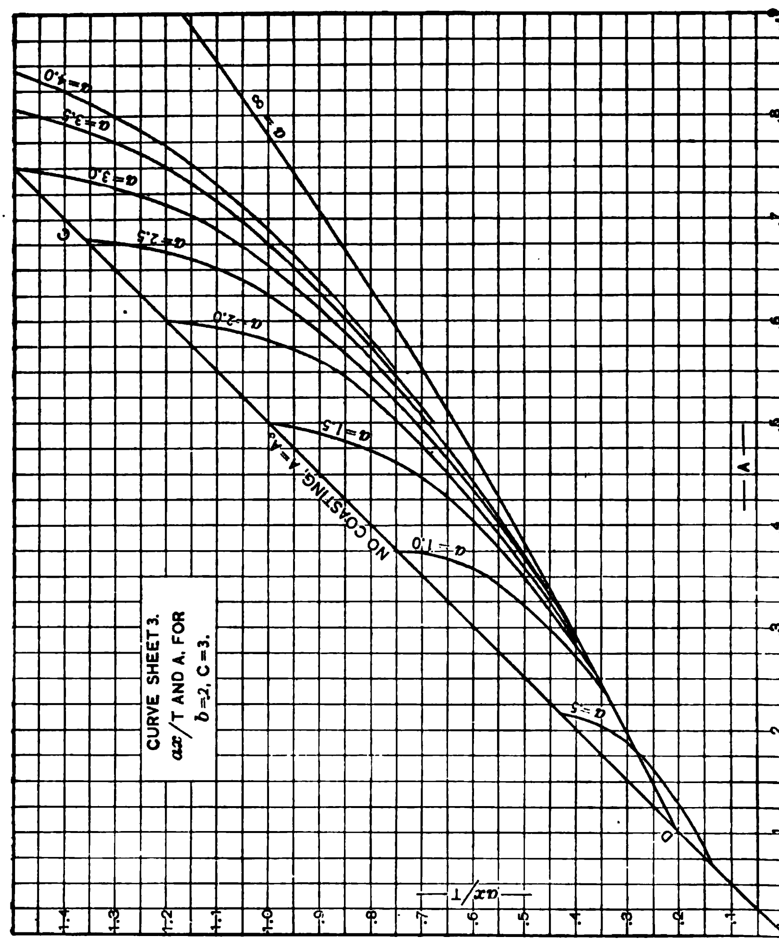
The power per ton is

$$P = 0.182\,(a + b)\,a\,x, \text{ kw} \tag{18}$$

Schedule Speed.—The relation of schedule speed S to average velocity V is dependent upon the time of stops at the station. If t is the time of stop at station, then

$$T = .682\, L/S - t$$
$$V = .682\, L/T$$
$$A = V/T = 1.47\, V^2/L \qquad (4)$$

These equations give A in terms of S and L. If t is taken at

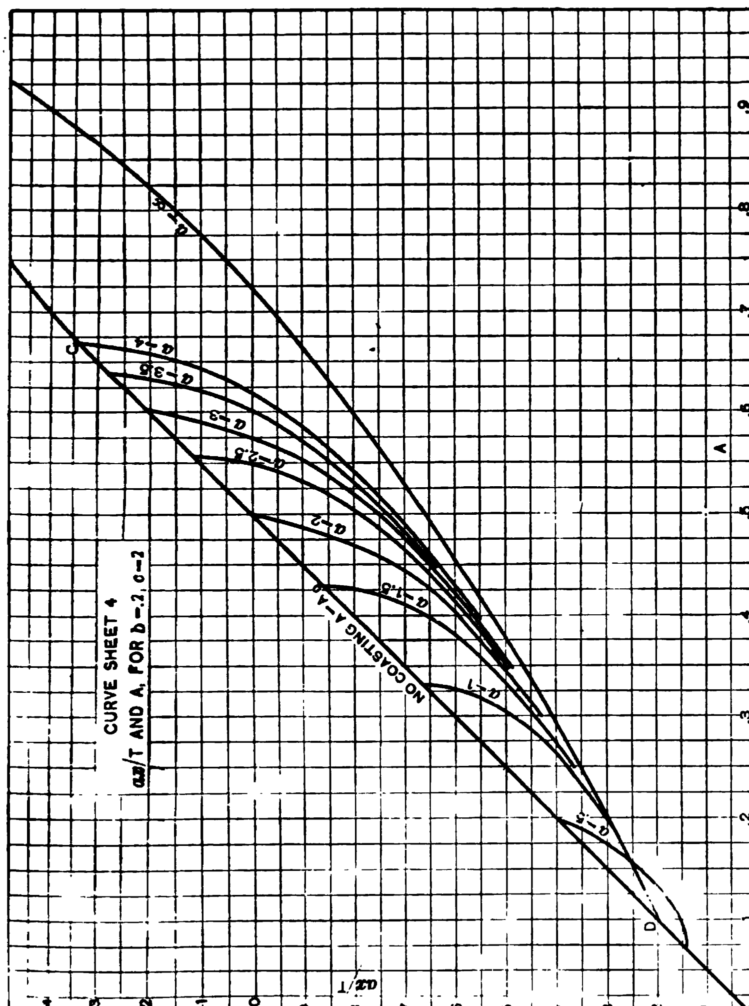


any constant value, curves can be plotted giving V in terms of S and L; it is, however, simpler to use the equations.

I do not consider the schedule speed further, but assume V and T to be determined from S, (t) and L. Knowing A, curve sheet 2 gives x/T and hence ($a\,x$) for any values of A. The energy and power are then determined by equations (17) and (18).

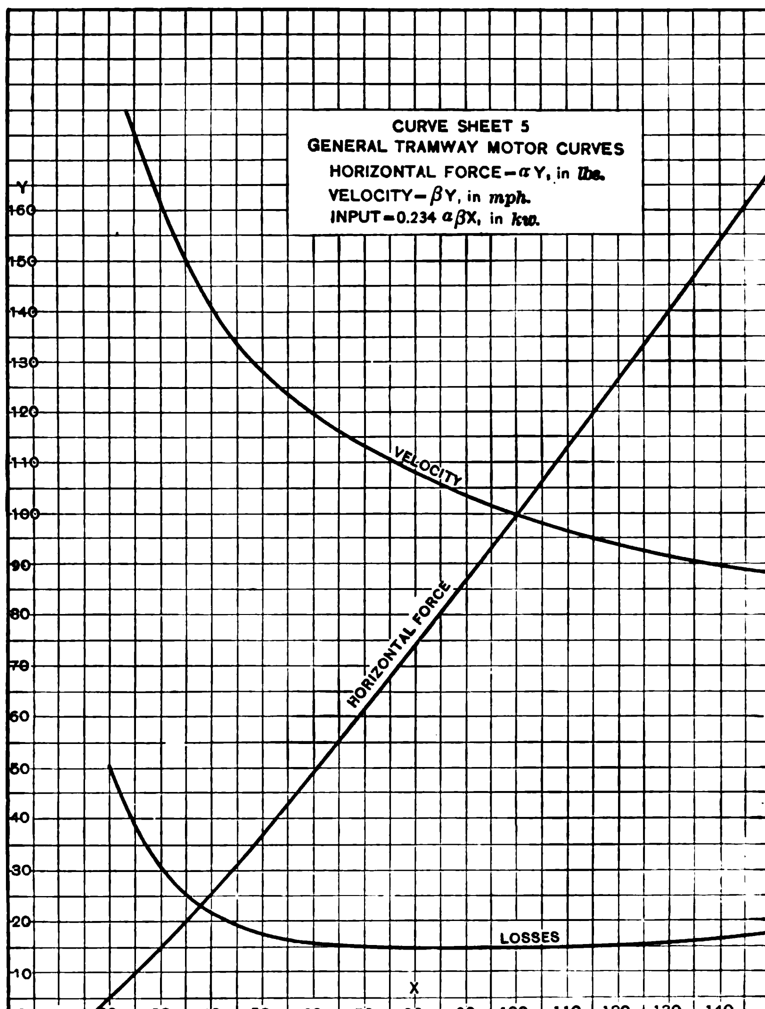
These quantities refer to the car axle and do not include losses of any kind in the motor, and hence are of theoretical interest only. If motors had constant efficiency, these values would be proportional to the energy input.

The discussion to this point is applicable to any kind of motive power. The matter of practical interest is the application to

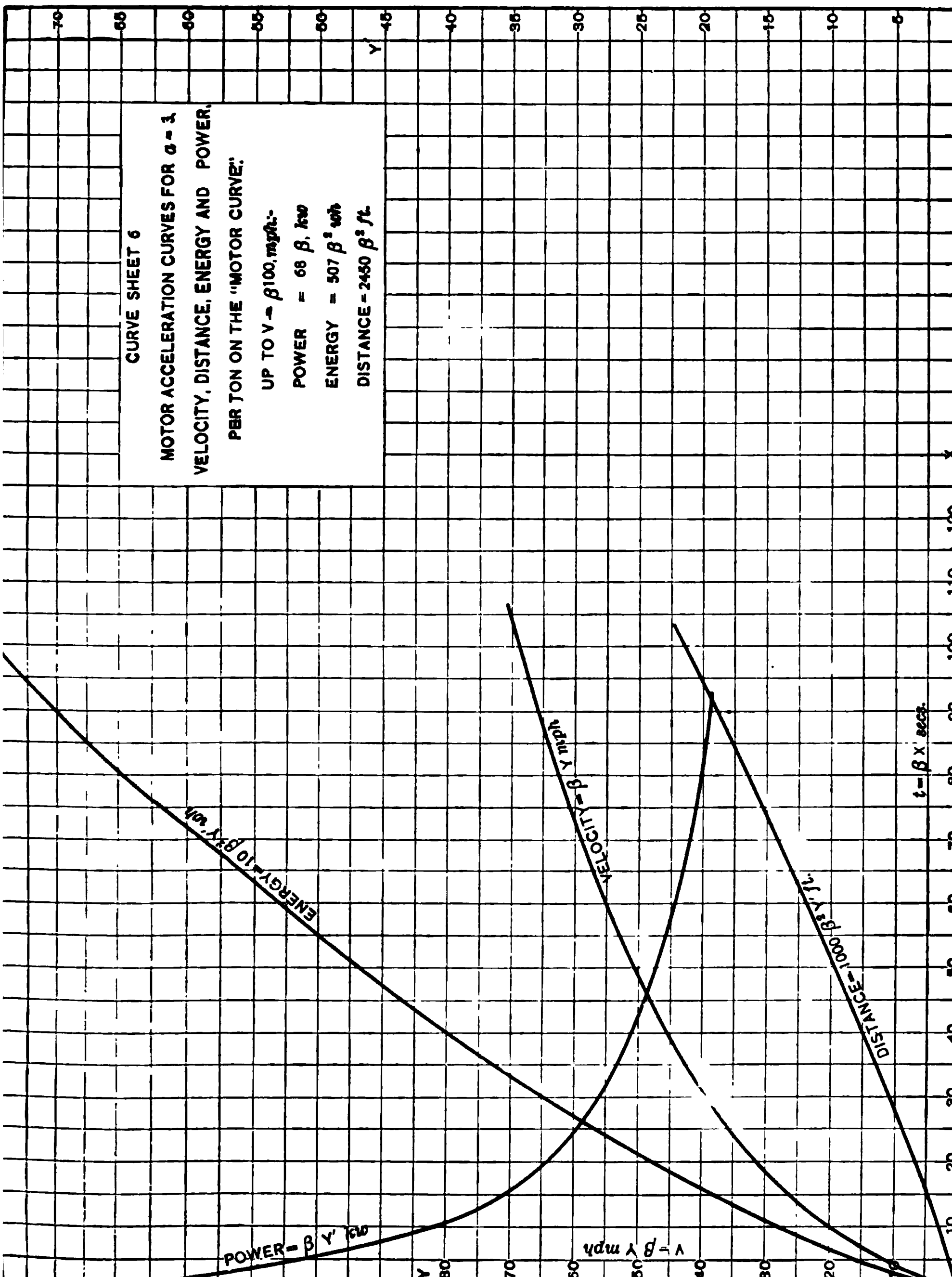


electric motors, and the determination of the quantities for the (v-t) curve of Fig. 2; the characteristics of the motor must be taken into account.

General Motor Curves.—In order to make the discussion general, it is not sufficient to consider one or two sizes of motor or one or two gearing ratios—all sizes and all gear ratios must be included, or what is the same thing, all values of torque at the axle and all values of velocity; in a word, a set of motor curves applicable to all sizes of motors must be prepared.



I have plotted the values of torque and speed in terms of input for some twenty tramway motors of different sizes and makes, expressing all quantities in percentage of their value at rated load, and find that the agreement is close—so close that one set of curves can with sufficient exactness for this purpose be used


CURVE SHEET 6
MOTOR ACCELERATION CURVES FOR a = 3.
VELOCITY, DISTANCE, ENERGY AND POWER,
PER TON ON THE "MOTOR CURVE."
UP TO V = β100, mph.:-
POWER = 68 β, kw
ENERGY = 507 β² wh
DISTANCE = 2450 β² ft.
ENERGY = 10 β² Y' wh
POWER = β Y' kw
VELOCITY = β Y mph
DISTANCE = 1000 β² Y' ft.
t = β X' secs.
V = β Y mph
X
Y
Y'

for almost any modern tramway motor built in the United States. It is immaterial whether this general motor curve represents any particular motor. By using this curve, the identically same characteristics are retained for all initial accelerations, hence the use of such a curve brings out the differences due to the different initial accelerations without complicating them by the differences in individual motor characteristics. Curve sheet 5 is this general tramway motor curve; abscissæ are input in kilowatts; ordinates are horizontal force (f) in lbs., and speed (v) in miles per hour; on these curves the rated load is the point (100,100) and is the rating on a one-hour basis, heating to 75° C.—the common tramway motor rating. Losses also are plotted; they differ much more in various motors than do (f) and (v).

Let $\beta\, Y'$ be the velocity and $a\, Y''$ the horizontal force, then every variation in conditions can be met by giving suitable values to a and β; this use of horizontal force and linear velocity eliminates the gearing ratio and size of wheel, both of which are determined by considerations outside of this discussion. Then for any value of X,

$$f = a\, Y'', \text{ lbs.}$$

$$\text{and } v = \beta\, Y', \text{ mph.}$$

The output is

$$[a\, \beta\, Y'\, Y'']/503, \text{ kw.}$$

and the input is

$$[a\, \beta\, Y'\, Y'']/(e \times 503), \text{ kw.}$$

where e is the efficiency at the point (X, Y', Y'') taken from the motor curve sheet. Choosing the point (100,100,100), the rated load, then $e = .85$, and the input is

$$P = 0.234\, a\, \beta\, X, \text{ kw.} \tag{19}$$

This determines the constant multiplier for the input in terms of a and β.

An example will make the use of these curves clear; suppose a motor is to exert a horizontal force of 2,000 lbs. at a speed of 20 mph.; if this is required at the rated load, then

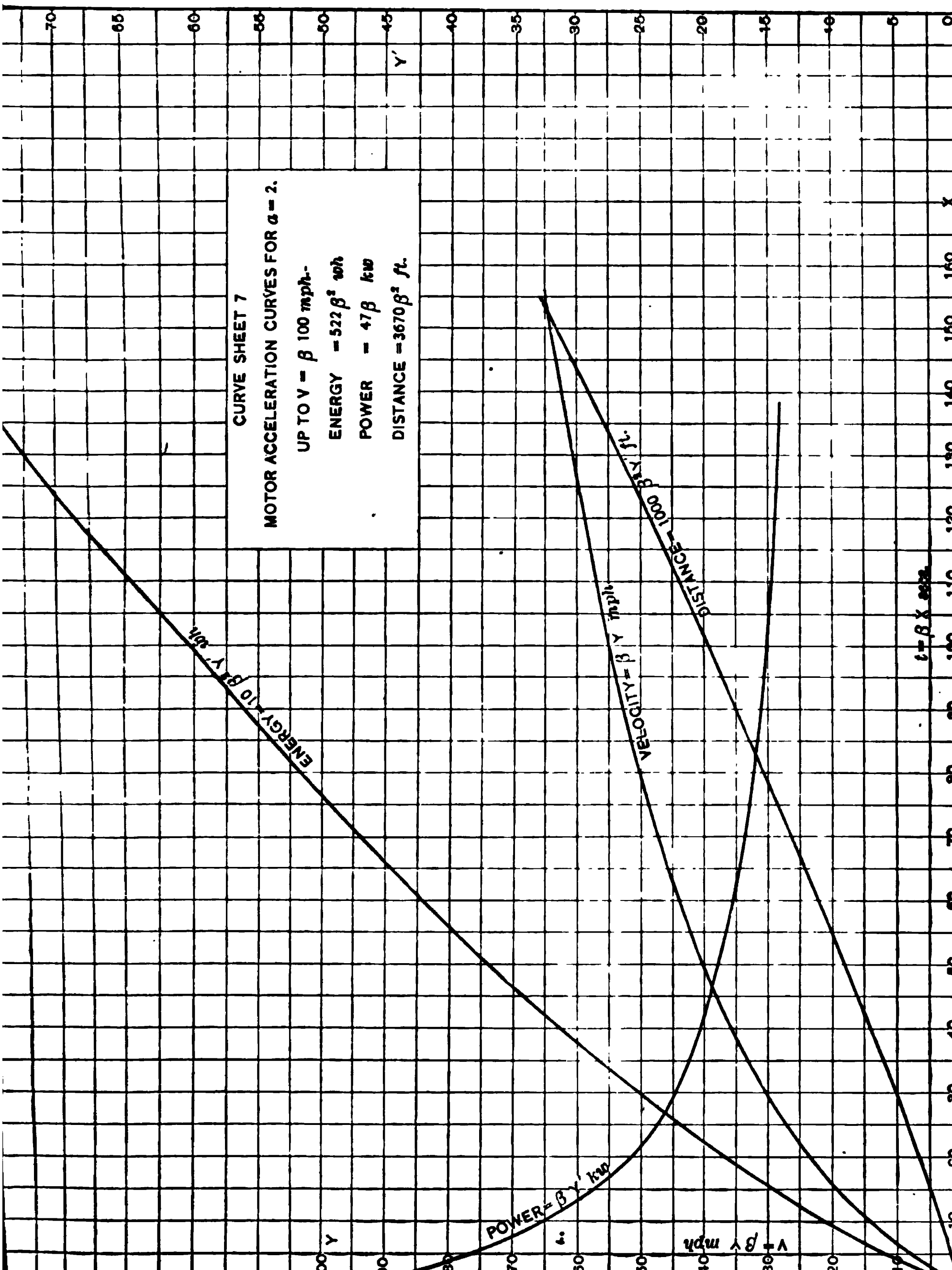
$$a = 20, \quad \beta = .2$$

and

$$P = 0.936\, X, \text{ kw.}$$

at rated load this motor is 93.6 kw.

It is not necessary to choose the point of rated load, any other point could be taken; for instance, a motor may be assumed to give 2,000 lbs. at 125% torque and 30 mph. at the corresponding value of the velocity, which is 93.8%; the motor is then carrying a load of 119%.


CURVE SHEET 7
MOTOR ACCELERATION CURVES FOR a = 2.
UP TO V = β 100 mph.
ENERGY = 522 β² wh
POWER = 47β kw
DISTANCE = 3670β² ft.
ENERGY = 10 β Y' wh
VELOCITY = β Y mph
POWER = β Y' kw
t = β X secs
V = β Y mph
X
Y
Y'

The gear ratio, size of wheel and motor capacity must be mutually adjusted to give the required force and velocity at the chosen point of motor input.

I assume in what follows that α and β are chosen for rated load; this matter is discussed further under the head of motor rating.

Acceleration Curves.—M (Fig. 2) is the point where the external resistance is all out of the circuit, and the motors begin to run on the " motor curve." The force exerted along O M is proportional to $(a+b)$. Assume this force to be the rated force of the motor and represented by the point $Y'' = 100$ on the general motor curve. The velocity at M is the rated velocity, is represented by $Y' = 100$, and is equal to β 100 mph. The acceleration on the motor curve continues to a point N, where the velocity is $\beta\, Y'$, Y' having any desired value greater than 100. The shape of the curve M Q N depends on the relative values of (a) and (b). If a/b is large, the curve is steep; if small, flat. This curve is determined as follows:

The force at any point on the curve, as Q, is

$$\text{Force} = \frac{w}{g}\,[dv/dt + b] = a\, Y'' \tag{20}$$

where Y'' is the ordinate of the (f) curve of sheet 5. For $Y'' =$ 100 at rated load and point M,

$$d\,v/dt = a$$

hence

$$a = \frac{W}{g} \times \frac{(a+b)}{100} \tag{21}$$

and

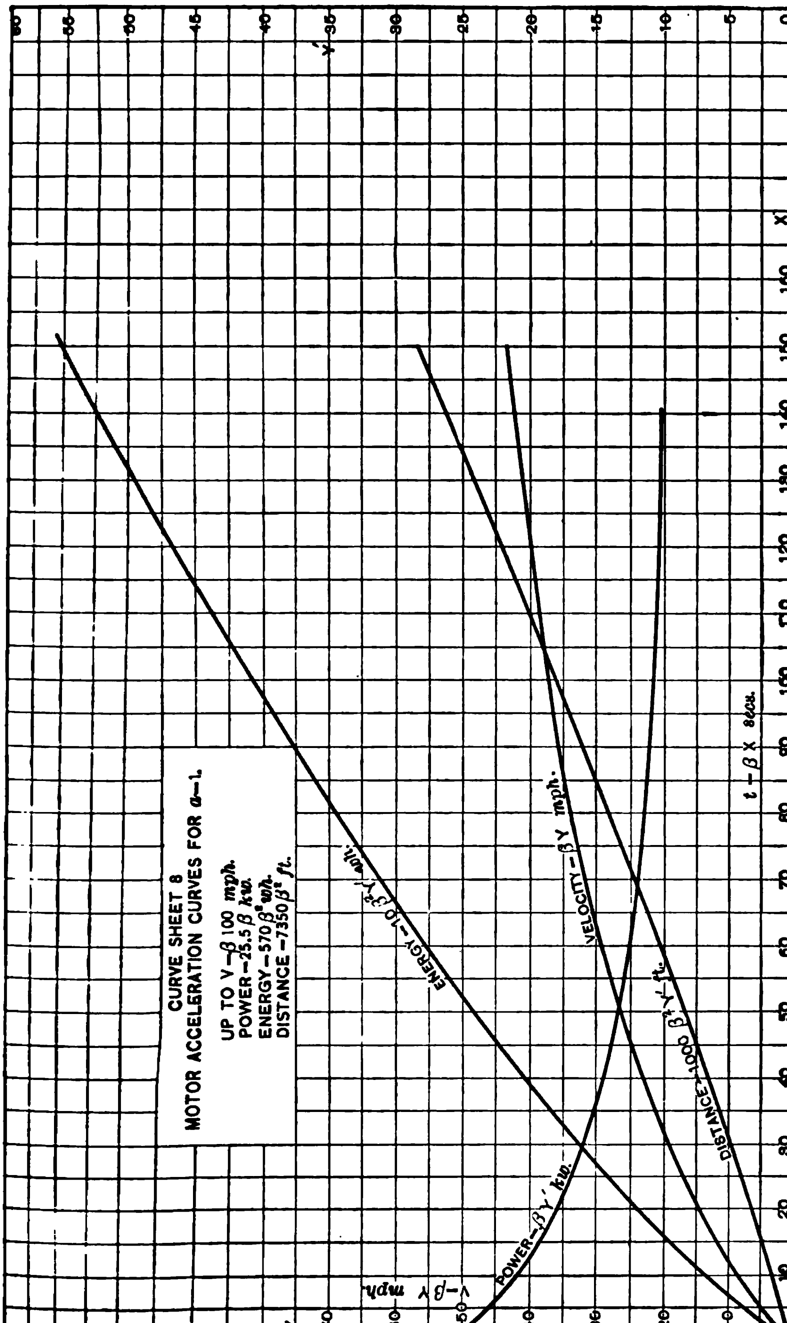
$$d\,v/dt = \frac{(a+b)}{100}\,Y'' - b$$

But $\quad d\,v/dt = \beta\,[d\,Y'/dt] = \beta\,[\Delta\,Y'/\Delta\,t]$

and hence $\quad \Delta\,t/\beta = \Delta\,Y'/[(a+b)\,Y''/100 - b] \qquad (22)$

From this equation, $\Delta\,t/\beta$ can be calculated for different values of (a) and (b), by taking from the velocity curve of sheet 5 $\Delta\,Y'$, and the corresponding values of Y'', the average force ordinate for the interval, $\Delta\,Y'$. Other methods may be used to calculate this tangent curve.

The values of $\Delta\,t/\beta$ are calculated and summed up. Plotting these values as abscissæ in terms of velocity as ordinates, a set


CURVE SHEET 8
MOTOR ACCELERATION CURVES FOR a=1.
UP TO V—β 100 mph.
POWER—25.5 β kw.
ENERGY—570 β² wh.
DISTANCE—7350 β² ft.
ENERGY—10 β² Y' wh.
VELOCITY—β Y mph.
POWER—β Y' kw.
DISTANCE—1000 β² Y' ft.
t—β X secs.
V—β Y mph.

of curves is obtained for each value of (a) which I call the acceleration or $(v\text{-}t)$ curve of the motor. The input corresponding to each velocity can be plotted on the same sheet, forming a (kw.-time) curve, and from the last by integration, an energy curve. Also from the $(v\text{-}t)$ curve, by integration, a curve of distance and time can be plotted. This gives a set of curves for each value of the initial acceleration, showing at once the power, energy, velocity and distance up to any relative velocity on the motor curve.

The deduction of these curves and their constants is as follows: From (19) and (21) and for $w = 2{,}000$ lbs.

Power.—$P = 0.213\,(a+b)\,\beta \times X$, kw./ton (23)

where X is the abscissa, taken from curve sheet 5 for any velocity.

Energy.—Similarly,

$$W = \frac{1000}{3600} \int_{v=\beta 100}^{v=\beta Y} P\,dt, \qquad \text{wh./ton}$$

and substituting from (23)

$$W = 5.92 \times 10^{-2}\,(a+b) \int_{100}^{1} Y\,dX, \qquad \text{wh./ton} \qquad (24)$$

Y and X are the co-ordinates of P on the several acceleration sheets.

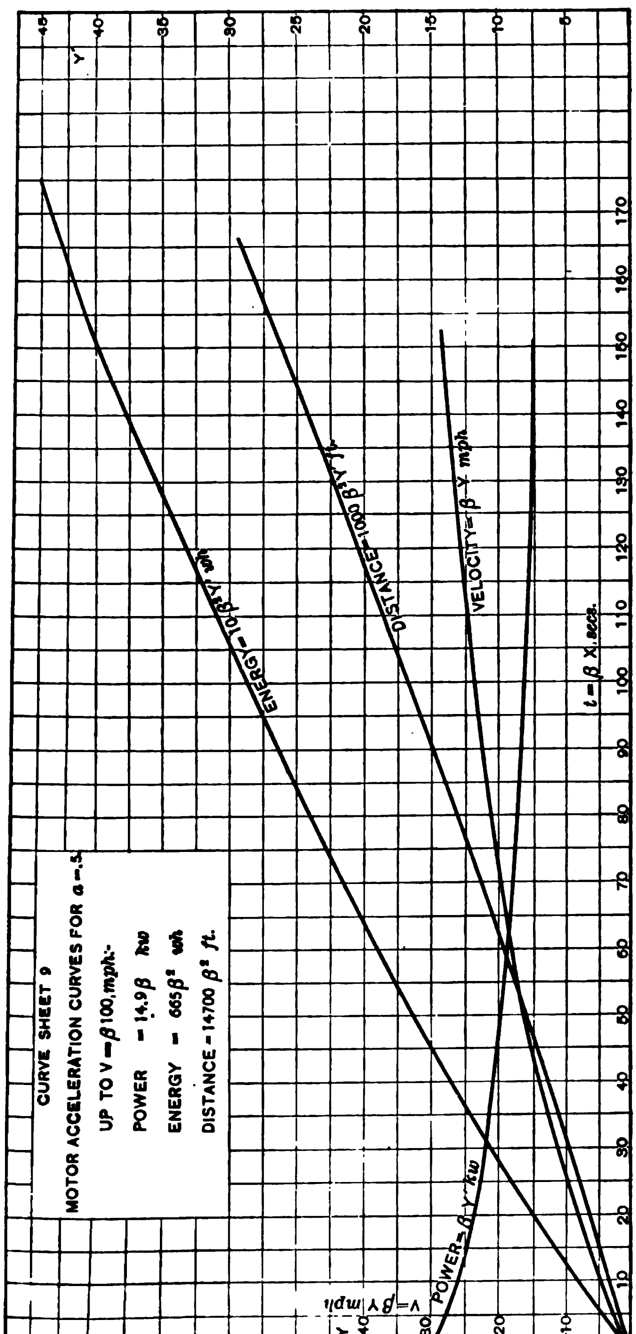
Distance.—

$$S = 1.467 \int v\,dt = 1.467\,\beta^2 \int_{100}^{Y} Y\,dX \qquad (25)$$

where Y and X are the co-ordinates of (v) on the several acceleration sheets.

Curve sheet 6 is calculated and plotted from equations 22, 23, 24 and 25, for $(a) = 3$. It shows velocity, distance, power and energy per ton in terms of time; the curves all start at $v = \beta 100$; that is, the energy and distance are for the motor curves, and do not include energy and distance up to velocity $v = \beta\,100$.

Curve sheets 7, 8 and 9 give the same quantities for $(a) = 2$ 1, and 0.5 respectively.


CURVE SHEET 9
MOTOR ACCELERATION CURVES FOR a = .5
UP TO V = β 100, mph:-
POWER = 14.9 β kw
ENERGY = 665 β² wh
DISTANCE = 14700 β² ft.
ENERGY = 10 β² Y' wh
DISTANCE = 1000 β² Y' ft.
VELOCITY = β Y mph
POWER = β Y kw
t = β X secs.
V = β Y mph
Y
Y'

The coefficient a has disappeared from these curves, only β, the velocity coefficient, remains. Power and velocity are proportional to β; energy and distance to β^2.

As an example of the use of these curves, take $a = 3$, curve sheet 6. For a motor to have a rated velocity of 20 mph., $\beta = 0.2$; after a time $X = 70\,\beta = 14$ seconds, the velocity will be $159\,\beta = 31.8$ mph.; the power $21.0 \times \beta = 4.20$ kw.; the energy used on the motor curve —$590\,\beta^2 = 23.6$ wh., and the distance traversed on the motor curve, $14{,}250 \times \beta^2 = 570$ feet.

From these (v-t) curves, Fig. 4 is drawn, on which the line O M represents the initial acceleration continued to the velocity $v = \beta\,100$, where the acceleration on the motor curve begins and continues to any point N; the velocity R N is made anything within practical conditions; coasting begins at N and continues to B, where brakes are applied. The ordinates multiplied by β give the velocity, the abscissæ multiplied by β give the time; hence, the inclination of any line on this diagram is independent of β.

Correction to Type Curve:—This discussion and the curve sheets deduced from it, determine all the elements of the type curve, O A B C. This type curve bears a certain relation to the motor curve O M N B C. The distance traversed in the first case will be greater than in the second by the equivalent of the area M A N. It is then possible to reduce each case for the motor curve to a corresponding case for the type curve by applying a correction, calculated in the following manner:

Determine the area M A N of Fig. 4 for each (a), and for any desired number of points on the motor curve; call this area Δ; then $1.47\,\beta^2\,\Delta$ is the distance in feet represented by the area.

Let

Y_t be the maximum velocity A D on the type curve;

Y_m be the maximum velocity R N on the motor curve;

A be the through acceleration on the type curve:

A_m be the through acceleration on the motor curve;

and

X be $\overline{\text{O C}}$;

Then

$$L = L' - 1.47\,\beta^2\,\Delta$$

$$\beta^2 A_m X^2 = \beta^2 A\, X^2 - \beta^2\,\Delta$$

or

$$A_m = A - \Delta / X$$

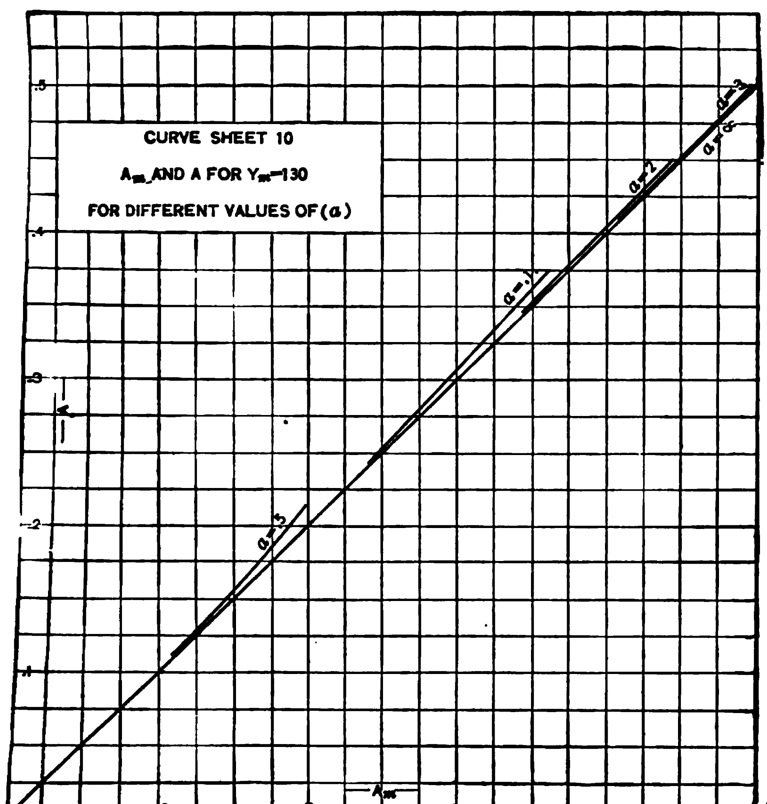
Put

$$\lambda = a\,x/T = Y_t\,/X \tag{26}$$

then

$$A_m = A - \Delta\,(\lambda/Y_t)^2 \tag{27}$$

Y_t is found from curve sheets 6, et seq., and λ from curve sheet 2, for any values of A, (a) and Y_m; A_m is then calculated, and plotted in terms of A, using the values of Δ previously calculated.



The values of A_m for all values of A, Y_m and (a), have been determined in this way; the corrections for values of Y_m less than 130 are too small to be taken into account; as I shall show, the minimum energy required for all schedules and for all values of (a), is practically at $Y_m = 130$; in some cases greater values of Y_m give slightly less energy, but the difference is so trifling that I have used only this value in discussing the energy relations.

Curve sheet 10 shows A_m in terms of A, for $Y_m = 130$, and for the different values of (a).

Maximum A_m:—The maximum A_m is evidently attained when acceleration is continued to the braking point and is represented by O M N C′ (Fig. 4). To calculate this maximum, O R is found from curve sheet 6 et seq., R C′ from the known values of R N and (c);—then R C′/O C′ $= z/T$.

Curve sheet 2 gives at once the values of A, and curve sheet 10, the corresponding A_m. The values so calculated for Y_m = 130 only; are given on curve sheet 11.

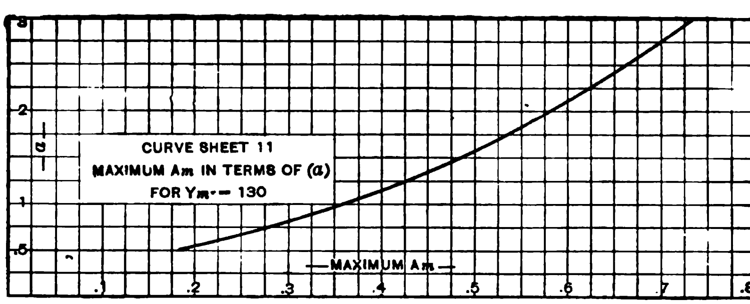
An example best shows the use of these curves:

Suppose

Schedule speed = 16.5 mph.

Distance between stops = 2,000 feet.

Time of stop = 15 secs.



Then,

Total time from start to start = 82.4 secs.

Running time = 67.4 secs.

Average velocity, V = 20.2 mph.

$$A = V/T = .3$$

Curve sheet 11 shows that (a) must be greater than .75; take $a = 1$; then curve sheet 8 determines the velocity curve up to the point N (Fig. 4): for $Y_m = 130$, curve sheet 10 gives A = .305 and from curve sheet 2,

$$x/T = .477$$

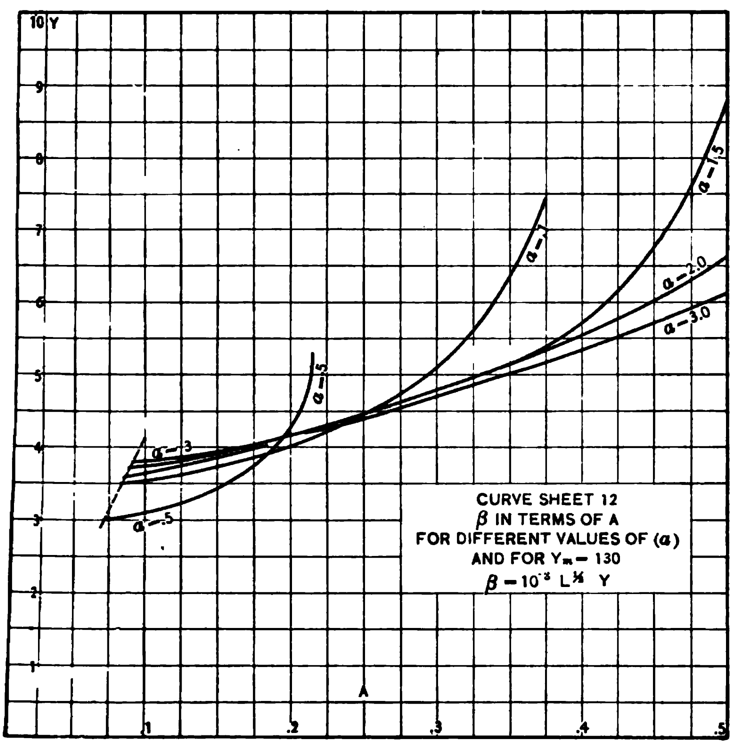
$$y/T = .130$$

$$z/T = .393$$

Maximum velocity on type curve $= .477 \times 67.4 = 32.3$ mph.

Maximum velocity on motor curve = $32.2 \times 130/136 = 30.7$ mph. Velocity at braking = $3 \times .130 \times 67.4 = 26.3$ mph.

Energy Input.—The energy at the car axle has already been determined; the electric input depends upon the method of motor control and the efficiency of the motor. I assume that series-parallel control in two steps is used. The power at the axle



at rated velocity, that is, point M, is then $0.85\ P_0$, where P_0 is the rated power. and the power at the axle is proportional to the speed. The change from series to parallel is assumed to occur at half speed; the efficiency of the motors will be about 70% when in series and carrying rated current. With these figures the input up to $v = \beta\ 100$ is

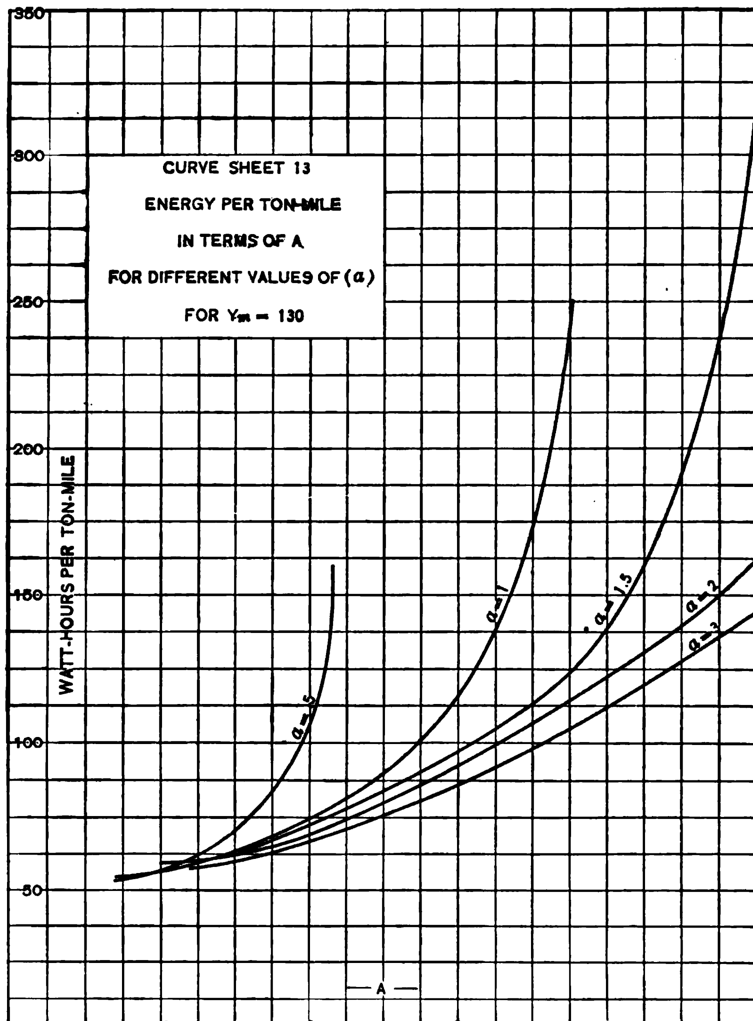
$$W_0 = .8\ P_0\ t_1 \tag{28}$$

and the output is

$$W' = .425\ P_0\ t_1.$$

hence the efficiency up to rated velocity—while resistance is in circuit—is 53%.

Substituting for P_0 its value from equation (23), and $t_1 = 100/\beta$, the input of electric energy per ton up to the point M is



$$W_0 = 475\,(1 + b/a)\,\beta^2 \qquad (29)$$

The values calculated from this equation are included on curve sheets 6, 7, 8 and 9, giving the energy up to the point $v = \beta 100$.

The input from the point M to the point N on the motor curve, is taken directly from curve sheets 6 et seq. depending upon the initial acceleration.

Velocity Constant, β.—Energy, power and distance all involve the velocity constant β. The values of β can be expressed in terms of the distance traversed, for all values of the through acceleration, as follows:

$$.682\, L = A\, T^2$$

$$T = \beta X$$

and

$$X = Y_t - / \lambda:$$

hence

$$\beta = \left(\frac{.682\, L}{A}\right)^{1/2} \times (\lambda / Y_t) = \left(\frac{.682\, L}{A}\right)^{1/2} \frac{a}{Y_t} \frac{x}{T} \qquad (30)$$

The energy used is proportional to the product of β^2 by the ordinates of the energy curves on sheets 6 et seq. There will, therefore, be a different multiplier for each value of (a) and of Y_m.

Limiting the discussion to $Y_m = 100$ and $Y_m = 130$, the following table gives the values of the energy per ton in terms of β.

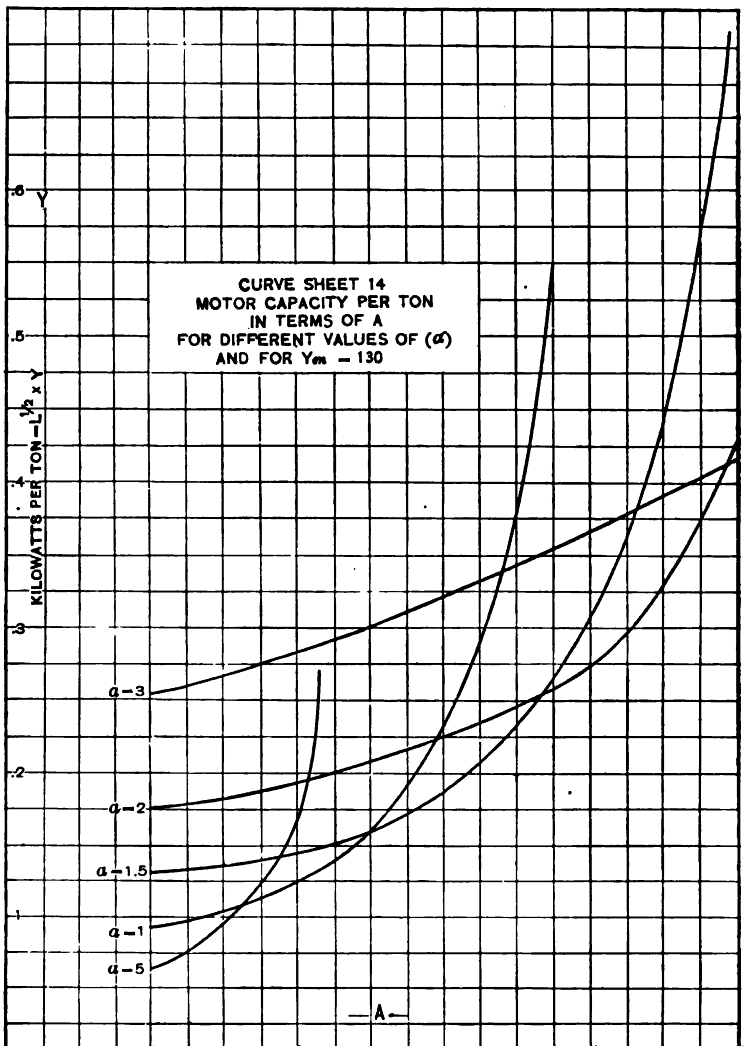
TABLE I.

Energy up to $v = \beta\, 100$ and $v = \beta\, 130$

(a)	$v = \beta\, 100$	$v = \beta\, 130$
.5	665 β^2	1115 β^2
1.	570 "	865 "
1.5	535 "	800 "
2.	522 "	767 "
3.	507 "	732 "

From equation 30, β can be calculated for all values of A and (a), and for all values of Y_m. The simplest way to calculate these values is, first to assume values of A and (a); then since $Y_m = 130$, Y_t is fixed. The value of x/T is taken from curve sheet 2.

β is proportional to $L^{1/2}$; β^2 to L; hence the energy used is proportional to the distance for any given value of A. The values of β have been calculated from this equation for all values of Y_m; I give here, however, a curve sheet showing these values



only for $Y_m = 130$, for the reason explained below.

This sheet covers the entire range of values of β for $Y_m = 130$, from the minimum to $A = .5$; this value of A is greater than is possible in practice.

The energy for all schedules can now be calculated by multiplying β^2 from curve sheet 12 by the constants given in Table 1. The values so calculated for Y_m = 130, are plotted on curve sheet 13.

I have calculated the energy consumption in this manner for all values of Y_m, and for the different values of (a) and of A, up to Y_m = 160. To give all these results is of no value, since the result shows that in nearly all practical cases the energy input is substantially a minimum for Y_m = 130. Table 2 below shows the relative energy for different values of Y_m for (a) = 2, in terms of energy for Y_m, = 130 as 100%, for the various values of A.

TABLE 2.

Relative Energy for Different Use of Motor Curve for (a) = 2 in Terms of Energy for Y_m = 130 as 100%.

Y_m	A				
	.5	4	.3	.2	.1
160	——	102%	97%	91%	89%
150	104%	101.5	98	93	93
140	100	100	99	95.5	95
130	100	100	100	100	100
120	103.5	106.5	106.5	105.5	105
110	110	112.5	113	112	108
100	119	122	121	128	120

This table is a fair example; it shows that the difference between the energy for 130 and greater values of Y_m is comparatively small. In the rest of this discussion, I use this value of Y_m only, and the values of β are for this reason given only for Y_m = 130.

Curve sheet 13 gives at once the answer to all questions regarding the energy required for any schedule; it shows clearly how slight is the saving in energy effected by the use of rapid accelerations. For instance, for A = .25, the energy for an acceleration of one mile per hour per second is 17.2 wh.; for an acceleration of 3 mph./sec., it is 14.5 wh.; that is, increasing the acceleration in the ratio of three to one diminishes the energy required only 16%.

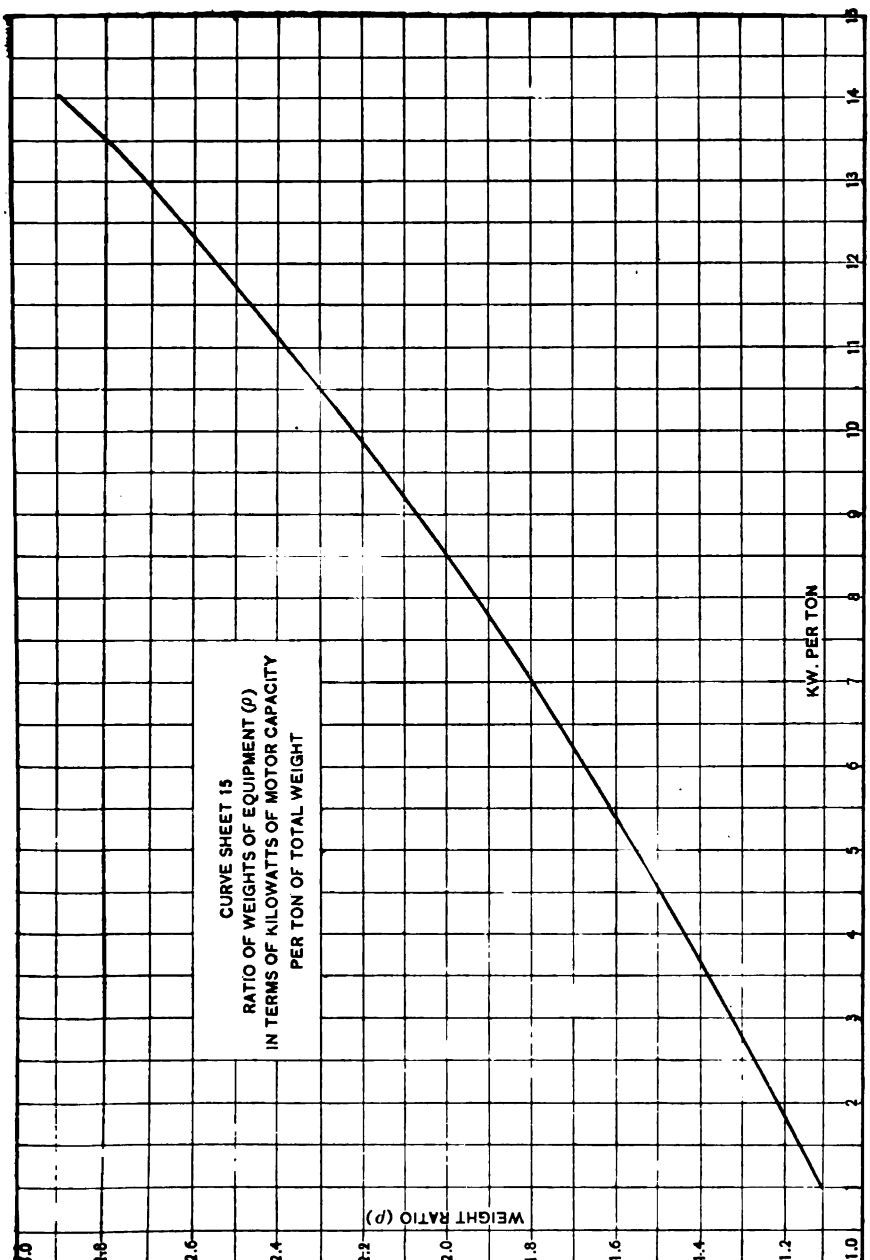
Motor Capacity.—This discussion has been based throughout on the assumption that the motor operates at the rated capacity on the one-hour basis, when at the point M (Fig. 4). On this assumption, the following table gives the capacity of the equipment required.

TABLE 3.

(a)	$P_0 = \beta X$
.5	14.9 kw/ton
1.	25.5 "
1.5	36.3 "
2.	47. "
3.	68. "

These are the starting values of the power curves on sheets 6, 7, 8 and 9, and may be considered the rated capacity of motors required, in so far as this rating is determined by commutation. Taking into account grades and curves and the possibility of various emergency requirements, I think it conservative to say that a motor should not be designed to operate above its one-hour capacity under the conditions here assumed; that is, on straight, level track, with frequent stops. The capacity of the motor depends also upon heating, and in most cases this is the ruling consideration. Hence it becomes necessary to determine the amount of heat liberated in the motor under all conditions of initial and through acceleration.

Heat Losses.—Referring to Fig. 4, the heat losses in the copper up to the point M are directly proportional to the time, since heat is liberated at a constant rate. The magnetic flux density in the motor is constant up to this point; if the core loss were proportional to the speed, the average loss would be one-half of the loss at rated speed; on the other hand, if the core loss were proportional to the square of the speed, the average loss would be one-third of the loss at rated speed; hence the average core loss


CURVE SHEET 15
RATIO OF WEIGHTS OF EQUIPMENT (ρ)
IN TERMS OF KILOWATTS OF MOTOR CAPACITY
PER TON OF TOTAL WEIGHT
KW. PER TON
WEIGHT RATIO (ρ)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

up to the point O M is between 33 and 50 per cent. of this loss at rated speed. The actual variation of the core loss with speed lies between these two values; I assume it to be equal to 41.0% of the loss at rated speed. It is of comparatively little consequence whether it be taken at 33 or 50% or at any intermediate value, since the core loss at rated speed is less than 30% of the total heat loss at rated speed; considerable errors in its values are of little moment.

I find from an examination of a number of modern tramway motors that at rated output P_0 the average core loss is 3.4%, and the average copper loss 8.6%—a total for the average loss of 12 %, excluding friction losses. These losses are the average of a somewhat different group of motors from those used in preparing the general motor curve, hence the small loss left for friction; for this last group the efficiency is 83% instead of 85%. The variations of the separate losses in the different motors is, generally speaking, small, although in certain motors the disparity is greater. The average loss up to $v = \beta\, 100$ is then 10% of the rated capacity, and is independent of initial acceleration.

From M to N on the motor curve, I have determined the losses from curves of separate losses; for the same group of motors the average of the total heat loss from $v = \beta\, 100$ to $v = \beta\, 130$ is 8.5% of the rated capacity.

Up to $v = \beta\, 100$, the average loss is 10% of P_0; for $v = \beta\, 130$, the values of t_1 and t_2 are taken from sheets 6, 7, 8 and 9, and the average loss over the total time $(t_1 + t_2)$ calculated; it will be found to be constant for all values of (a), as it should be, and equal to 9.4% of rated capacity.

The average rate of heat dissipation will be:

$$.1\, P_0, \text{ up to } v = \beta\, 100$$

$$\text{and } .094\, P'_0, \text{ up to } v = \beta\, 130$$

The rates continue for the times t_1 and $(t_1 + t_2)$, respectively; during the rest of the cycle the motors are radiating heat; hence these rates referred to the total time T, are

$$.1\, t_1/T \times P_0, \text{ up to } v = \beta\, 100$$

$$.094\, (t_1 + t_2)/T \times P'_0, \text{ up to } v = \beta\, 130,$$

and as percentages of the rated capacities in the two cases, are

$$10\, t_1/T\% \qquad \text{up to } v = \beta\, 100 \qquad (31)$$

$$9.4 \times (t_1 + t_2)/T\% \qquad \text{up to } v = \beta\, 130 \qquad (32)$$

These are the average rates for the entire time from start to stop, and by comparison with the average loss that such a motor will stand continuously without excessive heating, determine whether the motors would be running above or below their rated capacity; or conversely, determine what the capacity on a one-hour basis must be, so that when operating in this way they will not over-heat.

Equation (32) can be written

$$9.4\,(1+t_2/t_1)\,t_1/T\%$$

But (Fig. 4)

$$t_1 = \overline{OP} = OD \,.\, MP/AD$$

$$= x \times 100/Y$$

$$\text{and } t_1/T = x/T\,(100/Y)$$

hence the total heat loss up to the velocity β 130 averaged over the entire time T is

$$9.4\,(1 + t_2/t_1) \times 100/Y \times x/T\% \qquad (33)$$

where x/T is taken from curve sheet 2 for the proper values of A and (a). In this deduction it is assumed that $A_m = A$.

Hour Rating.—The one-hour rating of a tramway motor is much in excess of the continuous capacity; approximately such a motor will carry its rated output for 25% of the total time, that is, for one minute out of four; the heat generated at rated capacity for one-quarter of a complete cycle will bring it to its rated temperature. It is assumed that the cycles are repeated at such intervals that a permanent regime is attained. This is only an approximation, but is a fair one, if the percentage be more or less than 25, and the conclusions can be altered to accord.

As the average heat losses at rated load are 12%, it follows that such a motor can dissipate continuously 3% of its rated capacity; when the average rate is over 3% the motor is overloaded.

Since the average loss that a motor will stand is equal to 3%, it follows that the maximum value of (x/T), or $(x/T)_0$ is

$$(x/T)_0 = 3/[9.4\,(1+t_2/t_1)] \times Y/100$$

Curve sheets 6, 7, 8 and 9 give then

TABLE 4.

(a)	$(x/T)_0$
.5	0.249
1.	0.260
1.5	0.265
2.	0.270
3	0.271

For $Y_t = 100$, the limiting value is $(x/T)_0 = .3$, for all values of A and (a).

This means that for schedules in which $x/T > .3$, in one case, and for $x/T > .249$ et seq. in the other, the capacity must be greater than the capacity determined by commutation; that is, greater than the values of Table 3 in the ratio of $(x/T)/(x/T)_0$; for $x/T > .3$, or less than the values of Table 4, commutation determines the capacity.

The motor capacity necessary both to avoid overheating and to keep within commutation limits, can now be calculated from these data. Table 3 gives the capacity required on the assumption that commutation is the only limit to output, and on the further assumption that the hourly rated capacity is the practical limit determined by commutation. These values, multiplied by the ratio $(x/T)/(x/T)_0$ give the capacity in all cases, with the limitation that the capacity shall not be less than that of Table 3. Then,

$$\text{Motor capacity} = 14.9\,\beta \times (x/T)/(x/T)_0 \text{ for } a = .5 \qquad (34)$$

and, $$\text{Motor capacity} > 14.9\,\beta \text{ for } a = .5$$

The coefficient for other values of the initial acceleration is given by Table 4.

The capacity of the motor, as determined by this equation, has been calculated for all values of A and (a), and curve sheet 14 gives the kilowatts per ton, considering both commutation and heating, for $Y_m = 130$.

For the lowest acceleration $(a) = .5$, heating is the limitation for all values of A; for the higher values of (a), commutation is the limitation for the low, and heating for the high, values of A.

I wish to emphasize the conditions under which these capacity curves were obtained; (1) that the limit of input determined by commutation is the rated capacity, and (2) that the limit determined by heating is an input that will average for the total time 3% of rated capacity in copper and core losses. I am aware that motors are operated at much greater inputs than the rated capacity in regular service, but for service requiring frequent stops this is not unduly low, if low maintenance cost is taken into account. It is easy to follow out this argument with any desired overload at starting; the results will be but slightly affected.

Similarly, with reference to heating, 3% is not a sacred figure, but only a fair average; it is easy to make the changes for any other value. No changes within practical limitations will affect the relative results for different schedules and initial accelerations; the absolute values only will be slightly changed.

As this entire discussion has been based on the assumption that the input of the motor along the line O M of Fig. 4 (that is, during the period of constant acceleration) is its rated capacity, it would seem at first glance, that the increase of capacity necessitated by heating conditions, would vitiate all the deductions given here. This however, is not the case. The velocities are in no way affected; hence the energy at the car axle is unaltered. The only change brought about by using a motor that does not operate at its rated capacity during the initial period, is a change in the heat losses in the motor. This will not affect the energy input greatly, since almost the entire losses during this period are losses in external resistance; hence, the curves showing energy required per ton mile will be substantially unaltered. Such change will in all cases increase the heat waste in the motor, hence the capacity, given on curve sheet 14, will in all cases be somewhat too small. On the other hand, the capacity so calculated is greater than necessary, as no allowance has been made for heat radiation during the time of stop at stations.

Another consideration leads to the same result. As I have shown, the energy used per ton mile varies very slightly for any amount of acceleration on the motor curve from 120% to 160%. To use a motor at other than the rated capacity means that the motor is operating on a different part of the motor curve; hence the difference in energy input will be small.

Weight of Equipment.—These curve sheets show that the motor capacity for high initial accelerations is generally greatly in excess of the motor capacity required for low initial accelerations. Greater capacity of equipment necessarily means greater weight of equipment, not only in the motors themselves, but also in the trucks, controllers and other parts. This entails the further necessity of more energy to carry this greater weight; each addition of weight means a further addition to the energy necessary. To get a correct comparison of the total energy per mile required for different initial accelerations, the values of curve sheet 13 should be multiplied by the ratio of the necessary weights in the two cases. For instance, for an initial acceleration of 3 mph./sec., the total weight of equipment may be 25% greater than for an initial acceleration of 1 mph./sec.; the total energy used per mile will then be increased in the ratio of increase of the weights.

I have taken the weights of all parts of a car equipment in detail for different capacity of motors, varying from 30 to 150 rated H.P., for both two and four motor equipments. These weights include motors, controllers, trolley poles, car wiring, motor trucks, trail trucks and car body. I have deduced from these weights, curve sheet 15, on which the ordinates show the ratio of weights for different capacity of equipment, in terms of kw./ton of total weight as abscissæ. For instance, for an equipment of 4 kw./ton of total weight, the ratio is 1.44; for an equipment of 8 kw./ton, the ratio is 1.93; the increase of equipment from 4 to 8 kw./ton then increases the total weight in the ratio of $1.93/1.44 = 1.34$; that is, doubling the equipment means an increase of 34% in total weight; hence, 34% in total energy used. The ordinates of curve sheet 13 giving energy per ton mile, multiplied by the ratios from curve sheet 15 for the different capacity of equipments, determined by curve sheet 14, will be proportional to the total energy required per mile.

The capacity of the equipment is proportional to $L^{1/6}$ and as the distance will vary in each case, it is not possible to deduce any general results; each case must be considered by itself, in this particular. I have made these calculations for a number of cases to correspond with practical conditions; the result is always that the energy used per mile is less for the lower acceleration.

As an example:

Let

$$V = 16.5 \text{ mph.}$$

$$L = 2{,}000 \text{ feet.}$$

then

$$A = .2$$

From the various curve sheets, the following table is deduced:

TABLE 5.

a	kw/ton	wh./ton	ρ	$\rho \times$ wh./ton.	
				wh	%
.5	7.6	106	1.87	198	174
1.	5.6	75	1.63	114	100
1.5	6.5	73	1.73	126	111
2.0	8.7	70	2.03	142	124
3.0	12.6	67	2.65	177	156

The last column of this table shows the energy required per mile to be the minimum for an acceleration of 1 mph./sec.; the motor capacity is also at a minimum for this acceleration.

To take the case of the proposed express service of the New York Rapid Transit Line: here the schedule speed will be 35 mph.; the average distance between stations, about 7,500 feet; time of stop at stations, 15 seconds.

From these data,

$$V = 38.8 \text{ mph.}$$

$$\text{and } A = .275$$

The following table is deduced from these data:

TABLE 6.

a	kw./ton	wh./ton.
1.	16.7	102
1.5	14.9	82
2.	18.8	72
3.	26.9	62

This table shows the practical impossibility of accomplishing such a schedule on the assumptions of this discussion. The minimum motor capacity required of 14.9 kw./ton, is beyond the range of practical conditions. The weight of motors, controllers and wiring, that is, the electrical equipment alone, will be about 75 pounds per kilowatt, and the weight for 14.9 k.w would be about 1,140 pounds. This does not leave sufficient weight for the other parts of the equipment. For an acceleration of 3 mph./sec., the weight of the motors required, 26.9 kw., would be approximately one ton; that is to say, at this initial acceleration, the motors would just be able to propel themselves.

Conclusions.—My conclusion from this discussion is that the acceleration that gives the lowest motor capacity per ton is generally the most economical. The very small saving in energy is not to be compared with the many disadvantages of very rapid initial acceleration. Assume, for instance, a gain of 10 watt-hours per ton mile for an acceleration of 3, over that required for an acceleration of 1; for a 20-ton car, and with energy at .5 cents per kw. hour, this represents a saving of .1 cent per car mile. This is too trifling to be considered in comparison with the fixed charges on the greater investment for motors and distribution system; the poorer load factor at the power station, the increased cost of maintenance, the difficulty of accurate handling of cars, and, above all, the much greater discomfort to passengers.

Although I have had to make in the course of this discussion, various more or less arbitrary assumptions, I believe that they are all fair ones, representing average conditions. It is open to any one to follow this method on such other assumptions as may suit his fancy. I believe, however, that no practical assumptions will change the general results.

A paper presented at the 160th meeting of the American Institute Electrical Engineers, New York, January 24, 1902.

A CONSIDERATION OF THE INERTIA OF THE ROTATING PARTS OF A TRAIN.

BY NORMAN WILSON STORER.

The problem of calculating the motor capacity and the amount of power necessary to maintain a certain train service involves a consideration of where all the power which is developed by the motors is expended; of just how much is used in overcoming train resistance; how much in overcoming the force of gravity, and how much in overcoming the inertia. The train resistance is a variable quantity depending on the track, bearings, wind and speed. A considerable number of formulæ have been produced to assist in calculating the train resistance under different speeds, but at the best the amount to allow for train resistance is only approximate. The energy required to overcome the force of gravity and the inertia of the train, however, is susceptible of the most exact calculation, but the latter is seldom estimated correctly. There is one element in the inertia factor which has been almost entirely neglected, either because it has not been recognized at all or because its importance has not been appreciated. This feature is the inertia of the rotating parts of the train.

It has been generally understood that armatures of small diameter and light weight are desirable because their small fly-wheel capacity makes easier braking, but it has seldom been considered that this means also less power developed by the motor. A recent investigation of this subject has led to some very interesting results. It is found that the wheels, with their low speed, and the armatures, which usually revolve at a much higher rate than the wheels, together constitute an important element in the determination of the power required for operating the train. A specific instance will show this most clearly. Take the case of a double-truck car weighing 30 tons loaded. It has eight 33-inch wheels weighing about 700 lbs. each, and two motors rated, we will say, at 150 h.p. each. The radius of gyration of the wheels is about 77 per cent. of the radius of the wheel. The center of gyration of the wheel, therefore, moves at a rate 77 per cent. of that of the train. The flywheel effect of each wheel then is equal to a weight of $700 \times 77^2 = 415$ lbs., when reduced to the speed of the car. Eight wheels will, therefore, add 3,320 lbs. to the inertia weight of the car.

The armatures have each a flywheel effect of 1,400 lbs. at a radius of 6 inches. With a gear ratio of 18: 53 the center of gyration of the armature will move a distance of 925 feet for every revolution of the axle, or for a corresponding movement of the car of 8.6 feet. Its relative speed, is, therefore, $\frac{9.25}{8.6} = 1.08$ times the car speed, and the flywheel effect is therefore $1,400 \times 1.08^2 = 1,640$ lbs. reduced to the car speed. The two armatures thus add an equivalent weight of 3,280 lbs. to the inertia weight of the car.

The wheels and armatures together add an equivalent of $3,320 + 3,280 = 6,600$ lbs., or about 11 per cent., to the inertia weight of the car.

The following paragraph will show the effect of a change in the gear ratios:

With a gear ratio of 20 : 51 the flywheel effect of the armatures would be equivalent to the addition of 2,400 lbs. to the inertia weight of the car. This, together with that of the wheels, adds a total of 5,720 lbs., or about 9.5 per cent., to the inertia weight of the car.

From a considerable number of instances that have been taken, the flywheel effect of the rotating parts of an electric car is found to average about 10 per cent. of the inertia of the entire weight of the train. This means that 10 per cent. more energy is stored in every train than is accounted for by the dead weight; 10 per cent. more power is required for accelerating; 10 per cent. more energy is lost in braking, and the train resistance measured by the retardation in coasting is 10 per cent. below the true resistance.

The actual increase in energy supplied to a train on account of the flywheel effect of the rotating parts is the energy in these parts which is lost in braking. The relation this bears to the total power developed by the motors is dependent on the number of stops, the speed at the time the brakes are applied and on the energy absorbed by the train resistance. Where the stops are frequent, the energy lost in brakes may be from 50 per cent. to 75 per cent. of the entire power developed by the motors, in which case the energy required by the rotating parts will be from 5 to 7½ per cent. of the total.

There are two simple methods for including this item in the calculations. The first is by basing the calculations on a weight of car 10 per cent. heavier than the actual in determining the acceleration and drifting. The second is by assuming that the force required to produce a certain rate of acceleration is 10 per cent. higher than would be necessary if it were simply a dead weight. This is probably the simpler method, for it gives round numbers for calculations, as 10 per cent. added to 91.3 gives practically 100 lbs. per ton as the force required for accelerating at the rate of one mile per hour per second. All that is necessary then in correcting calculations for accelerations is to use this figure of 100 lbs. per ton instead of 91.3. It will give a good average correction, although if great accuracy is desired it will be preferable to calculate the flywheel effect of each of the rotating parts of the train separately. It will usually be found that for slower speed service, where the gear reduction is considerable, more than 10 per cent. will be required, while for high speed interurban work where it would really amount to very little anyway on account of the small number of accelerations, the amount to be added for the correction will be less than 10 per cent.

As will be readily recognized, this factor will also enter into the determination of the train resistance from the coasting line. Just how much of a correction will have to be made on this account depends somewhat on what is considered to be the train resistance. If this includes the friction in the motor then the train resistance obtained from the coasting line will be 10 per cent. lower than the actual train resistance. On this assumption, if the retardation in coasting is .2 miles per hour per second, the train resistance will be 20 lbs. per ton instead of 18.2 as calculated by the ordinary method. If, however, the train resistance does not include the friction of the motor, the correction necessary to be made for inertia of rotating parts will be small, because it will be nearly balanced by the motor friction. When the train is coasting, the inertia of the rotating parts is added to the inertia of the dead weight of the train in tending to keep up the speed. When the train is accelerating, or moving with power on the motors, the motor friction is taken into account in the efficiency curve of the motor, so that the train resistance to be used in calculating the acceleration should properly not include the motor friction. It will thus be seen that the error due to motor friction and the inertia of the rotating parts will tend to counterbalance each other in the determination of the train resistance from the coasting line. For accurate determinations, however, the train resistance should include a consideration of both the inertia of the rotating parts and the motor friction. The most accurate way to obtain this is to plot the friction curve of the motor and to obtain the inertia of the armature and wheels either from tests or from calculations based on the drawings.

It may be considered that this is an undue refinement, but if the matter is carefully investigated it will be found that the motor friction is a considerable portion of the total train resistance, in the same way as the inertia of the rotating parts is a considerable portion of the inertia of the train.

It is understood that general solutions for the railway problem may be offered which will give fair approximations of the motor capacity and the amount of power required. It is understood that any good engineer with a fair amount of experience can give a pretty good estimate of the power required for a given service even when considering the capacity of the motor according to the old horse power rating. But where accuracy is required, every known element should be considered at its proper value and there will still be at best enough variable quantities in the railway problem. The most reliable estimate for train resistance should be used; the inertia of the rotating parts should be obtained and considered; the weight of the entire train should be known; the acceleration and power curves should be carefully plotted and the average heating effect in the motors should be accurately determined before any large equipment is finally decided upon.

A paper presented at the 160th Meeting of the American Institute of Electrical Engineers, at New York, January 24th, 1902.

THE SELECTION OF ELECTRIC MOTORS FOR RAILWAY SERVICE.

BY W. B. POTTER.

The excellent paper by Dr. Cary T. Hutchinson on the subject of energy and motor capacity for electric trains, shows a careful study of the problem, considered from an average basis. In discussing that paper I shall endeavor to point out some variations from the average met with in the practical consideration of motor selection.

It may be stated as a general proposition that for a given schedule the lowest power consumption will be secured with the lowest speed gearing that will ensure with reasonable margin the performance of the desired schedule. The torque per ampere is proportionately greater with the low speed gearing, and the maximum speed is also less; the first with respect to current fluctuations, due to improper handling of the controller, and the latter with respect to energy consumption, as influenced by the percentage of coasting, being less affected in their lower values by unskilled motormen.

Motormen will frequently keep the power on until they apply the brakes, regardless of the requirements of the schedule, and if gaining on the schedule, will apply the brakes to slow down midway between stops instead of allowing the car to coast, as they should do before reaching maximum speed. It is a well known and proven fact that different motormen, by reason of different percentages of coasting, may make a difference of at least 20% in the energy required for the performance of a given schedule. The less frequent the number of stops, the less will be the difference between different men. The difference may be taken approximately at 2% for each stop per mile, and the more nearly the calculated requirements approach the theoretical or best possible economy, the greater the allowance that should be made, as it is a fair assumption that none of the cars will be handled in a manner to secure the highest possible efficiency.

When a close calculation of the energy is desired, it is of advantage to use the actual characteristic of the motor under consideration rather than an average characteristic, not so much on account of the difference in power due to the characteristic alone, as on account of the shape of the speed curve, which may differ widely at free running speed with different types of motors.

The free running speed assumed by Dr. Hutchinson as 130% of the speed at which the external resistance is cut out, would imply that power was cut off before the car had attained full acceleration, and it would depend entirely upon the service requirements whether such would be the case. Even 160% is not sufficient for some motors. The free running speed will vary from 150% to 200%, the speed at which the resistance is cut out; that is, with motors of low saturation the car may double its speed on the motor curve.

The determination of motor capacity; that is, the motor heating in a given service, cannot with desired accuracy be obtained from the average of a number of motors. Dr. Hutchinson has assumed an average copper loss of 8.6% of a rated input. This will vary from 5% in the larger motors to 12% in smaller motors, and different motors of the same commercial horse power rating may vary 30% to 40%.

The average core loss has been assumed as 3.4% of the rated input, and this percentage between different motors will be found to vary between 2% and 5%, and with motors having the same commercial horse power rating; the core loss of some will be found to be double that of others. The following table will indi-

PERCENTAGE LOSSES OF INPUT AT RATED CAPACITY.

Commercial Rating.	Field. I^2R	Armature I^2R	Armature Core.	Armature Total.	Motor Total.
38 H.P.	4.70	4.00	2.37	6.37	11.07
38 "	4.60	3.80	4.92	8.72	13.32
50 "	4.20	2.10	3.45	5.55	9.75
50 "	4.33	3.36	4.17	7.53	11.86
50 "	3.25	2.80	4.80	7.60	10.82
75 "	3.20	2.50	2.93	5.43	8.63
125 "	2.48	2.40	2.12	4.52	7.00

cate some of the differences that actually exist between the motors of several different manufacturers.

The average service losses in the motor as a whole have been assumed as an average of 9.4% of the rated input, based on a maximum speed of 130%. This average, both with respect to percentage and maximum speed, will vary materially with the character of the service; on frequent stops it may be a total of 9.6% with 3.2% in the field, and 6.4% in the armature. With the same motor and infrequent stops the loss would be more nearly 3.4% with .6% in the field, and 2.8% in the armature. As between different motors of the same rating for the same schedule, the total loss may be found to vary 30% or more.

As between speed at rated capacity, and free running speed, the core loss of some motors is constant within 5%, while in other motors it may vary 100%, being less at full speed.

The assumption that a motor will run one-quarter of the time at its commercially rated input for its rated temperature rise is a fair average, but actually the time will vary from 20 % to 50% of the total time and depends on whether the motor is running closed or open, on the stand, or under service conditions. In consideration of the variations that exist between different motors, it would seem a reasonable assumption that calculated temperatures based on the average of a number of motors would not give the actual loss in the fields within approximately 20%, or the loss in the armature within approximately 40%, and combining these variations with the difference in radiating capacity of different motors, the result based on averages might not give the actual temperature rise within 100%.

The assumption that a motor as a whole will radiate continuously 3% of its rated input is also a fair average, the variation being approximately 2.5% to 3.5%. This, however, does not give the distribution of losses in the field and armature, which is important as affecting temperature rise, and from the above table it will be noted that the distribution differs widely with different motors.

The commercial basis of rating a railway motor, *i.e.*, "The horse power output giving 75° C. rise for one hour's continuous run at 500 volts on a stand with covers off," was selected several years ago by the writer after a careful consideration of what the commercial rating of a railway motor could reasonably be expected to cover.

This method serves the commercial necessity of a relative measure of capacity between different motors, and the current required to give a temperature rise of 75° C. in one hour insures a satisfactory test of commutation. It is further a desirably severe test of the mechanical and electrical design of the motor.

A criticism of this method of rating might be that the voltage should preferably be 550 instead of 500 volts, as 550 volts is now the more common voltage.

Seventy-five degrees C. rise was purposely taken as a higher temperature than railway motors should be operated in service, 65° C. rise as a maximum and 55° C. as an average being as high a temperature rise as is compatible with reasonable maintenance.

Before selecting this method, the subject was carefully studied with reference to giving a significant rating applicable to service conditions, but the difficulty of doing this will be appreciated when it is understood that a tabulated statement of any one motor with different gear ratios, weight of cars and stops per mile includes one hundred or more different schedules.

The use of motors too small for the service, with resultant burning out from overload, is inexcusable, for not only are they expensive to rewind, but the delays and annoyance to passengers incident to break down is above all things to be avoided. Reliability of service should be the primary consideration in every case.

The equivalent heating or reproduction of a given service by running the motor at the current giving an equivalent $I^2 R$ loss, and at the voltage giving the average core loss would be convenient and correct, providing the effective amperes of the given service are determined and applied at the proper voltage. The voltage at which such test should be made representing in effect the particular core loss for a given service will vary widely with motors of different capacities and even between motors of the same capacity having different core losses.

Such a method assumes that for a common service there is a certain current and voltage common to all motors of the same capacity, which, if run on a stand with this current and voltage, will produce in the motors equivalent losses and in their proper distribution, and that the temperature rise of the armature and field so obtained will closely approximate the temperature rise in actual service.

The speed curves of railway motors materially differ; that is, they have different saturation curves, and, as before mentioned, the maximum free running speed in motors of the same rating may differ 50% on the motor curve. Even assuming that the energy input in two cases is the same, the rate of input will not be the same, due to variations in the saturation curve; that is, the average current will be the same, but the current as affecting the heating, which is the square root of the mean square, will not be the same, unless motors have the same saturation curve. These variations lead to the conclusion that a common current cannot be taken for various motors for a given service, as, regardless of the gear ratio, the speed, torque and ampere constants of each motor will not coincide, unless they have a speed curve of the same shape, which is seldom the case.

As before mentioned, the core losses of motors having the same commercial rating may vary as much as 100%, some core loss curves being nearly constant in watt loss throughout the working range of the motor, while others at rated load may be double the watt loss at full speed.

The core losses are composed partly of eddy currents, varying as a square of the speed or voltage, and partly of hysteresis, varying directly as the speed or voltage, and the relative proportion of these two losses will vary greatly in different motors. It is not likely between different motors that the core loss of each will be composed of eddy currents and hysteresis in the same ratio; thus, the speed or voltage that would give the service core loss would be quite different with different motors.

In order that the same current and voltage shall apply to several motors of different design or manufacture for a given service, it is necessary that the motors be geared to exactly the same speed, that the motors shall have identically the same efficiency throughout, that the shape of the speed curve or saturation be identical, that the core loss curve be of the same shape, and be composed of eddy and hysteresis losses in the same proportion.

It is needless to add that such uniformity does not exist, and it only remains to determine how far the difference between similar types of motors of different manufacturers differ from each other. This is shown by the following table of motors of different manufacture, with the current and voltage to give the losses and their proper distribution, the motors being geared to make the same schedule. The acceleration is taken at 1.5 m.p.h. per second in every case.

Distance, 750 feet. Time, 54.4 seconds.

Commercial rating.	Amperes.	Volts.
35 h. p.	35.9	310
35 h. p.	33.6	344
38 h. p.	32.4	372
38 h. p.	33.4	351

Distance, 1 mile. Time, 227 seconds.

35 h. p.	24.6	478
35 h. p.	22.4	452
38 h. p.	22.4	458
38 h. p.	23.4	377

The above values for current and voltage would vary considerably with different percentages of coasting, and different schedules.

Owing to the complex character of the core losses and speed curve a large number of calculations, of which the above are representative, indicate the futility of comparing or determining motors by assuming an arbitrary voltage. The current and voltage must be predetermined for each particular motor and service.

This method of rating further assumes that the temperature rise and the distribution of temperatures in a motor run on the stand will hold good under service conditions. Experience does not indicate this to be the case. A motor with a ventilated armature will give more nearly the service temperature rise on a stand than a motor with poorly ventilated armature. Furthermore, with a large number of starts per mile, the motor is run either at relatively slow speed or not running at all for a considerable portion of the time, while with few stops on high speed suburban service the motor is relatively cooled by the long continuous run, with the result that in the first instance the stand tests may give lower, and in the latter, higher temperatures, due to the relative difference in radiation of the motor frame.

For such determination of the motor capacity as is essential to the recommendation of motors suitable for a given service, experience has shown the desirability of determining the losses and consequent heating of the field and armature independently for each particular case.

From a speed curve based on the acceleration and maximum speed required for a given schedule the proper gearing, winding and commutation of a motor suitable for the service can be obtained. Owing to different lengths of runs, slow-downs at curves, and the effect of grades, the speed curves of different runs over the line may, and usually do, differ materially. Having established the speed curves for a given service, the field and armature losses may be integrated by reference to the resistance and core loss curves of the motor under the varying conditions of control and running on the motor curve.

Having determined the average loss in the field and armature for a particular service, the next step is to determine the temperature rise of the field and armature under these conditions.

It is obvious that the most accurate means for determining the heating effect for different losses is to test the motors under service conditions at a known loss in the field and armature, and to measure the actual resultant heating.

To this end the motors should be mounted on a car and operated at various schedules and distances on a track, careful records being taken with recording instruments of the speed-time curves, amperes and voltage, the tests being continued until the motor temperature is constant. The temperature should be taken both by thermometer and by resistance, both with the motors closed and with the covers removed. From the known losses in the motor during these tests there may be determined the degrees rise per watt loss, both for the field and armature; the distribution of the losses in the two elements being represented by the watt loss in the armature divided by the watt loss in the field.

Having determined the ratio of losses for the particular service, a reference to the temperature tests for the particular motor and ratio of losses enables one to determine the degrees rise per watt loss for the armature and field. It is then a simple matter of multiplication to determine closely the temperature rise of the armature and field for the proposed service.

Several years' experience with different methods of determining motor capacity have shown this to be the only rational and reasonably accurate method, as it takes into account all the variable factors.

The following table has been calculated directly from results determined under service conditions as described above, and shows in tabulated form the capacity for a safe temperature of a 38 h.p. motor with different stops per mile, gear ratios and tons per motor.

LIST OF SCHEDULE SPEEDS FOR 38 H. P. MOTOR.

500 Volts. 33 in. Wheels. Straight and Level Track. 10% Margin Allowed in Schedule.

Stops per Mile.	Gear Ratio.	TONS PER MOTOR.									
		4	4.5	5	5.5	6	6.5	7	8	9	10
¼	4.60	22.3	21.7	21.2	20.9	20.5	20.2	19.8	19.3	18.8	18.5
¼	3.94	23.3	22.9	22.4	22.0	21.7	21.3	21.0	20.4	19.9	....
¼	3.42	25.0	24.6	24.2	23.7	23.2	22.8	22.4	...	...	....
¼	2.82	27.6	27.0	26.5	26.0	....	...	...	...	...	....
½	4.60	20.9	20.5	20.2	19.8	19.5	19.3	18.7	18.2	17.6	17.3
½	3.94	22.0	21.6	21.2	20.9	20.5	20.2	19.8	19.2	18.5	....
½	3.42	23.5	23.0	22.6	22.2	21.8	21.3	21.0	...	...	....
½	2.82	25.6	25.0	24.6	24.0	....	....	...	...	...	....
1	4.60	19.4	19.0	18.6	18.3	18.0	17.7	17.5	16.8	16.4	15.7
1	3.94	20.3	19.9	19.6	19.3	18.9	18.5	18.2	17.5	16.8	....
1	3.42	21.6	21.2	20.7	20.3	20.0	19.6	19.3	...	..	....
1	2.82	23.0	22.6	22.1	21.6	....	...	...	...	...	....
2	4.60	15.8	15.5	15.3	15.1	14.9	14.7	14.6	14.2	13.9	13.5
2	3.94	16.6	16.4	16.1	15.9	15.7	15.5	15.2	14.8	...	....
2	3.42	17.6	17.2	16.9	16.7	16.3	16.0	...	...	..	....
2	2.82	18.1	17.8	17.6	....	....	...	...	...	...	....
3	4.60	13.7	13.5	13.3	13.1	13.0	12.9	12.8	12.5	12.2	12.0
3	3.94	14.3	14.1	13.9	13.8	13.7	13.5	13.3	12.9	...	....
3	3.42	14.9	14.8	14.6	14.3	14.0	...	...	...	...	....
3	2.82	15.4	15.2	....	....	....	...	...	...	...	....
4	4.60	12.2	12.1	12.0	11.8	11.6	11.5	11.3	11.2	11.0	10.8
4	3.94	12.6	12.4	12.3	12.2	12.1	12.0	11.8	11.4	...	....
4	3.42	13.0	12.8	12.7	12.5	12.3	...	...	...	...	....
4	2.82	13.3	13.1	. .	...	...	...	...	...	...	....
5	4.60	11.1	11.0	10.9	10.8	10.7	10.6	10.4	10.3	10.1	....
5	3.94	11.4	11.3	11.2	11.1	11.0	10.9	10.7	10.4	...	....
5	3.42	11.8	11.6	11.5	11.3	....	...	..	...	...	....
5	2.82	11.9	....	....	....	....	..	..	...	...	....
6	4.60	10.1	10.0	9.9	9.8	9.8	9.7	9.6	9.5	9.2	....
6	3.94	10.4	10.3	10.2	10.1	10.0	9.8	9.7	...	...	....
6	3.42	10.6	10.5	10.4	10.3	....	...	...	...	...	....
6	2.82	....	....	....	....	....	...	...	...	...	....
7	4.60	9.4	9.3	9.2	9.1	9.1	9.0	8.9	8.4	8.5	....
7	3.94	9.6	9.5	9.5	9.4	9.4	9.2	9.1	...	...	....
7	3.42	9.7	9.6	9.5	....	....	...	...	...	...	....
7	2.82	....	....	....	....	....	...	...	...	...	....
8	4.60	8.8	8.7	8.6	8.5	8.5	8.4	8.4	8.3	8.2	....
8	3.94	9.0	8.9	8.8	8.8	8.7	8.6	8.5	...	...	....
8	3.42	9.0	8.9	8.9	....	...	...	...	...	...	....
8	2.82	....	....	....	....	....	...	...	...	...	....
Max. Speed *Dou Equip.	4.60	27.3		26.0		25.0			23.5		22.7
	3.94	29.0		27.5		26.5			25.0		24.0
	3.42	31.0		29.6		28.5			26.9		25.9
	2.82	35.0		33.5		32.3			30.6		29.5

*Speed of four equipment 5 to 10 per cent. faster for same tons per motor.

Such a method serves as a rapid, convenient and reasonably accurate method of selecting a motor within the variations covered.

This practical determination of the heating factors has led to marked improvements in the electrical design of motors, and the value and utility of these tests under service conditions can hardly be over-estimated in their application to practical conditions.

In closing I wish to express my thanks to Messrs. E. D. Priest and E. H. Anderson for their assistance in the calculations incident to the preparation of this paper.

SCHENECTADY, N. Y., Jan. 23, 1902.

Discussion.

President Steinmetz:—We all agree that Dr. Hutchinson's paper is only an approximation, and some of us think a rough approximation. The designing of railroad equipments five years ago, was all according to judgment and with an accuracy of say two or three hundred per cent. or so. At present, if we get accurate profiles of the road, schedule speeds, number of stops and all the data, and carefully investigate them, considering the characteristic curve of the particular motor which we intend to use, we can get very close, but between these two cases there is something more. We want to get an approximate estimate very much closer than the thumb rule estimate of years gone by, but still an approximation of general character, which does not need to be as close as might be required to fit each individual case, within a few per cent., and that is the thing which I believe the paper to supply. I now call upon Mr. W. C. Gotshall.

Mr. W. C. Gotshall.—Somewhat over a year ago the New York & Port Chester Railroad Company commenced an investigation upon heavy and high-speed electric traction. In the pursuit of this investigation there have been prepared by the engineers of the New York & Port Chester Railroad, and directly under the supervision of and by my associate, Mr. C. O. Mailloux, and myself, several hundred "run-sheets," the object of these investigations being, of course, to determine the economical and proper conditions of operation for the proposed service.

I received the advance copy of Dr. Hutchinson's paper a few days ago. After reading the paper, it was apparent to me that the results and conclusions arrived at by Dr. Hutchinson in this paper were diametrically opposite to those which we had obtained in the study of the technical details of electric train service proposed for the New York & Port Chester Railroad Company.

On account of the difference between the results which we obtained and the conclusions of Dr. Hutchinson's paper, I will here call your attention to a few of the typical run-sheets which have been worked out by us and which are now the property of the New York & Port Chester Railroad Company.

The paper which has been read purports to be, as stated in the first paragraph, a general solution covering all cases which can arise in ordinary practice of train movement, This statement is very broad—certainly broad enough to include, as a particular case, high-speed train movement such as would be required for rapid transit service. It is more particularly this aspect of the paper which I propose to discuss. It will be my purpose to confine this discussion to the fundamental points upon which the treatment of the paper rests, so far as I have been able to grasp them by examination of the curve sheets and by perusal of portions of the text. I may say that I am not quite prepared to look upon this solution as having a character and application quite as far-reaching as the author's statement would imply, for the reason that it fails to take into consideration some important points which generally involve and determine very important modifications in practical results. We all agree as to the desirability of finding and developing graphical methods for computing and analyzing the various factors and elements involved in the problem of train movement under certain given conditions. I am not prepared to believe, however, that it is wise to attempt a too broad or sweeping generalization by simplification at the expense of accuracy. The simplification is apparently obtained, in this case, by making many of the conditions a function of one principal, independent variable, which is called the " through acceleration " and designated by the letter A. Now, it is true that, in electric railroad work, as in other branches of our profession, in dealing with any problem we must always bear in mind the old adage that circumstances alter cases. These circumstances assume a difference in relative importance in many cases to such an extent that, while they may be of minor consideration in some cases, they become the primary consideration, or, literally, the independent variable, in other cases. Take, for instance, rapid transit work. In this case time is the paramount consideration; economy becomes a secondary one—contrary to the author's conclusion that economy of power is the sole governing consideration in the selection of an equipment. In high-speed work, the speed, in fact, is limited only by the absolute technical and commercial possibilities and impossibilities of the case.

If I interpret the author correctly, there are at least seven assumptions which he has made, apparently to simplify the mathematical treatment of the subject, which assumptions are apt to be fallacious in many cases and to require modification in almost all cases. These assumptions are the following:—

First. That the line be absolutely straight.

Second. That it be absolutely level.

Third. That the train resistance is constant at all speeds.

Fourth. That all runs for the entire length will not differ materially from the average length of run.

Fifth. That the power will be applied during the first part of the run only; that is to say, only on the first part of the speed-time curve.

Sixth. That the general type curve can be used with simple corrections for calculating the energy consumption under all conditions.

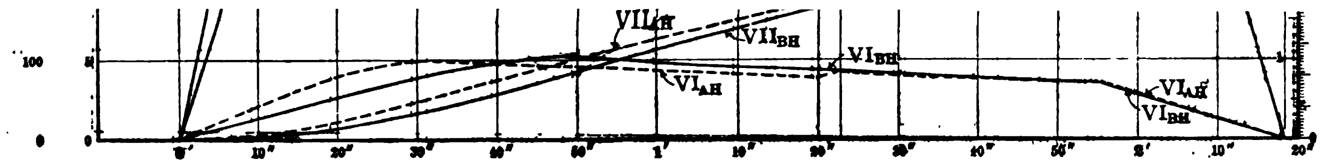
Seventh. That the rules and formulas applying to tramcar practice will also apply to rapid transit practice.

I do not think that the conclusions of Dr. Hutchinson, or his method of arriving at those conclusions, are at all applicable to practical conditions. In this paper Dr. Hutchinson has used and applied the letter A as a symbol designating what he chooses to call " through acceleration," which is a purely abstract idea, the physical meaning of which is not easy to realize. For the purpose of ascertaining what range of value this term may have, I have taken a number of typical runs for the New York & Port Chester Railroad as they have been worked out, and have determined the value for A for each of these runs. These determinations are shown in Table 1 in the column marked " A." The variations for the individual runs in the values of this quantity are very great, the difference being as much as 200 per cent. I believe that Dr. Hutchinson intends the value of A to be a sort of average acceleration factor. If such be the case, I call your attention to the fact that it would be impossible to arrive at any value of the average acceleration factor which could be used in practice from the results shown in Table 1. This is due to the material difference in the lengths of runs, as well as to the grades and curves which influence the maximum speed attained. In Table 1, under the column marked "angle," are shown the inclinations of the various acceleration lines. The column marked " coefficient " gives the numerical value of the " tangent " of the corresponding angle, which is equal to the corresponding rate of acceleration in m.p.h. per second. The variation in the value of these angles is undoubtedly of interest, but cannot be a matter of any great surprise. These variations might, indeed, have been expected, since any condition of the line other than a level condition must of necessity produce a different inclination for the line of acceleration, and, consequently, must determine a different value for the angle.

It may be well here to give a summary of the principal data in regard to this project. The project contemplates a four-track line running from the Harlem River to the Connecticut State line at Port Chester. Two of the tracks are to be used for express train traffic and two for local traffic. The total length of the main line, according to the present surveys, is 20.9 miles. The express trains will serve a total of eleven stations, making ten stops—the longest run being 3.114 miles and the shortest run 0.689 mile, and the average length 1.9 miles. The local trains will serve a total of twenty-two stations, making twenty-one stops. The longest local run is 1.853 miles and the shortest run (No. 10) is 0.428 mile, the average being 0.95 mile. The two main diagrams (Figs. 1 and 2) show the speed-time curves for local train runs No. 11 (Fig. 1) and No. 20 (Fig. 2). Some of the curves in Fig. 2 are reproduced separately in Figs. 2a and 2b. Table I gives various data in regard to the express runs. Table II gives certain data showing the influence of grades on the initial acceleration.

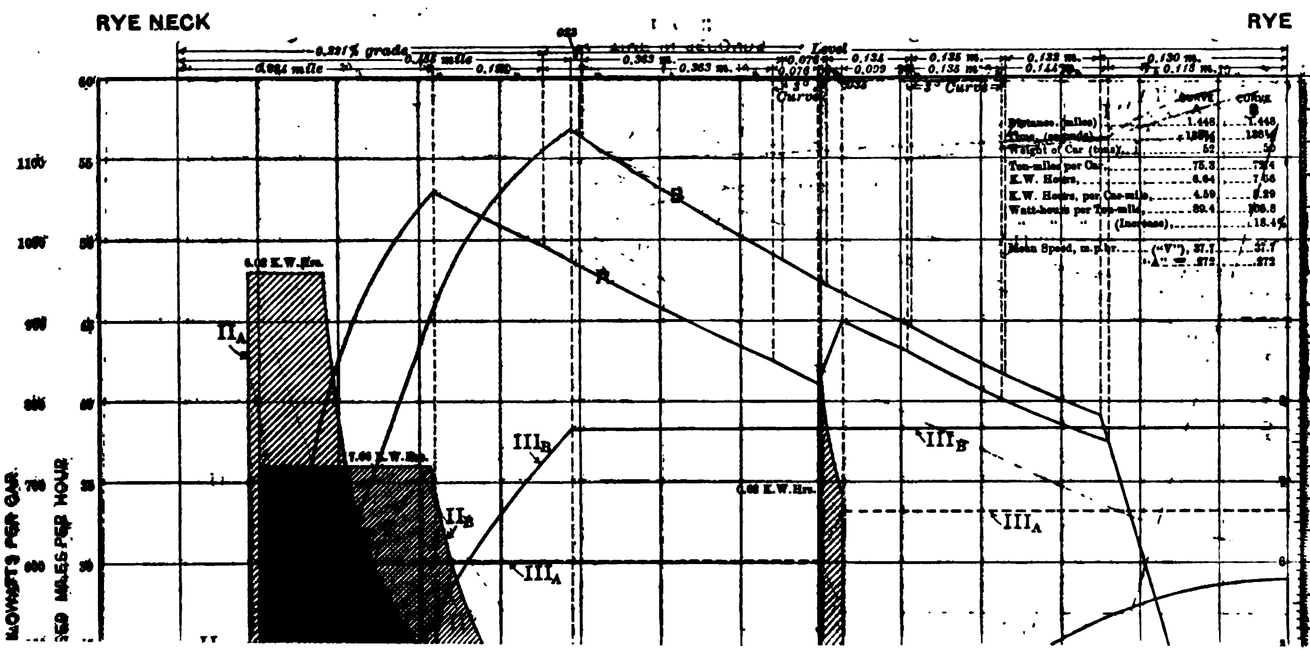
The schedule time proposed is thirty-one minutes for express trains and forty-nine minutes for local trains. The schedule speed is, therefore, 40.58 m.p.h. for express trains and 25.6 m.p.h. for local trains. An allowance of fifteen seconds is made for stops. The mean speed, or average velocity, is, therefore, 44 m.p.h. for express trains and 28.9 m.p.h. for local trains.

Each car is to be equipped with four motors, one on each axle, thereby making the entire weight available for traction. The



TIME IN SECONDS

Fig. 2b.



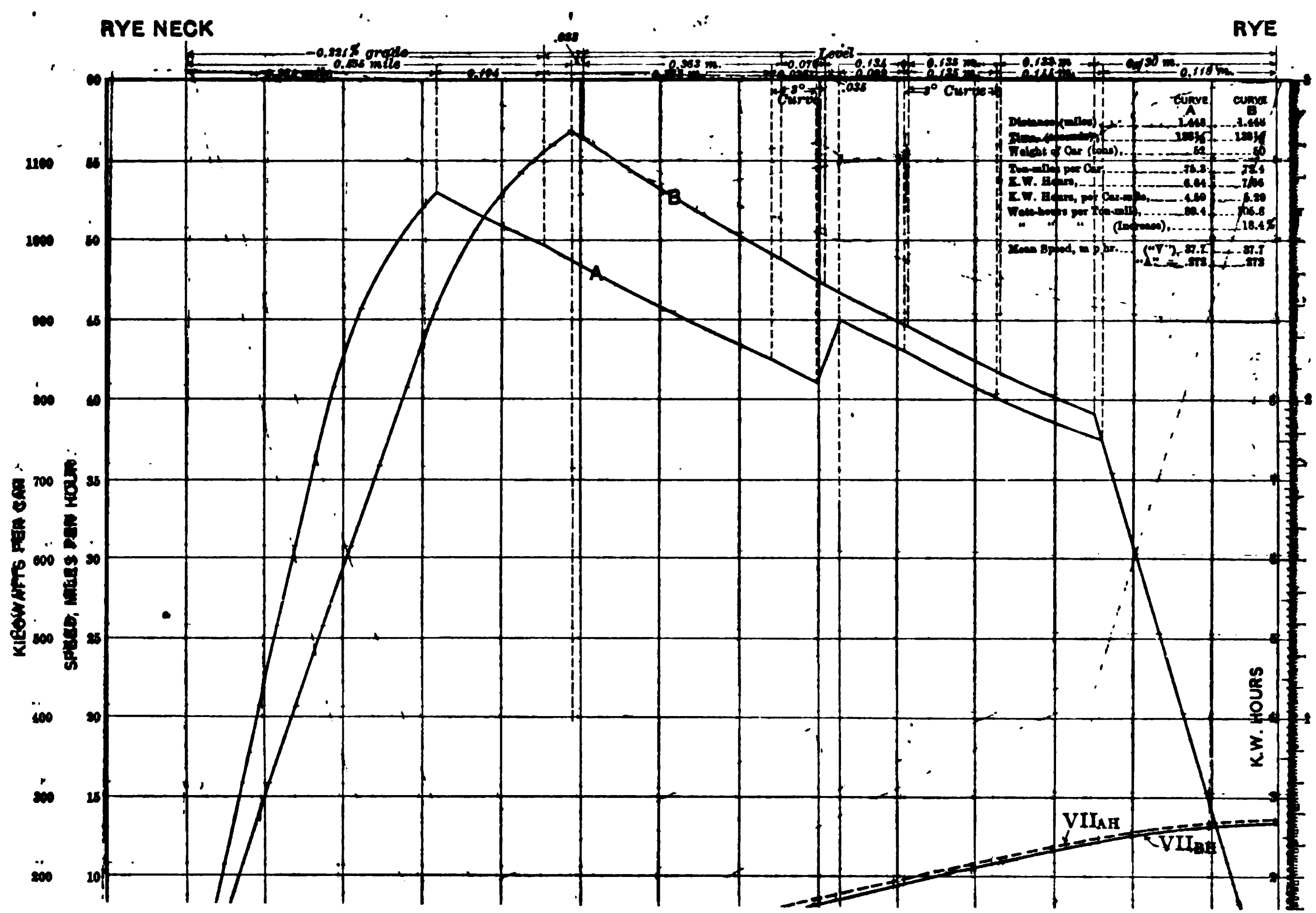

RYE NECK
RYE
0.221% grade
0.856 mile
Level
Curve A
Curve B
Distance (miles)
Weight of Car (tons)
Ton-miles per Car
K.W. Hours,
K.W. Hours, per Car-mile,
Watt-hours per Ton-mile,
(Increase),
Mean Speed, m p hr.
A
B
VIIAH
VIIBH
KILOWATTS PER CAR
SPEED, MILES PER HOUR
K.W. HOURS
MILES

TABLE I.

CONCERNING EXPRESS RUNS OF NEW YORK & PORT CHESTER RAILROAD

Run No.	From	To	Distance Miles	Time Seconds	Watt Hours per Ton Mile	Speed			Per Cent. Grade at Starting	Acceleration				
						Highest	Lowest	At Braking		Coeft.	Angle		V	A
											Deg	Min.		
1	Willis Avenue	149th Street	1.625	152½	160	57.5	25.0	59.7	....	2.15	65	5	38.35	.264
2	149th Street	Bronx Park	2.751	204	141	60.5	40.0	62.7	...	2.15	65	3	48.6	.238
3	Bronx Park	Bronx and Pelham Parkway	1.429	91½	169	60.4	60.4	60.4	+0.65	2.02	63	40	56 0	.614
4	Bronx and Pelham Parkway	Mount Vernon	3.104	218½	100	67 0	57.8	57.8	+0.163	2.12	64	45	51.2	.234
5	Mount Vernon	Pelham	0 689	72	172	53.3	50 0	50.0	—0.18	2 20	65	34	34.5	.479
6	Pelham	New Rochelle	1.843	166	142	54.5	38.4	50.3	+1.714	1.80	61	0	40.0	.241
7	New Rochelle	Larchmont	1 853	144	114	63.4	....	55.0	—0.90	2.36	67	2	46.35	.322
8	Larchmont	Mamaroneck	1.22	113½	158	57.6	42.7	55.0	+0.122	2.11	65	45	38.7	.341
9	Mamaroneck	Rye Neck	2 883	207½	111	62.7	41 7	55 4	—0.261	2.22	65	45	50 1	.2415
10	Rye Neck	Rye	1.45	105½	142	60.8	48 0	51.5	—0.22	2.21	65	39	49 5	.469
11	Rye	Port Chester	2.09	127	159	58.8	36.0	52 2	+0 424	2.26	66	8	59.2	467

total weight of car for express service, fully loaded, is 52 tons, of which 17 tons is the weight of the complete motor equipment. For the local service, another car has been under consideration having an equipment of four smaller and lighter motors, making the total weight of car 50 tons, with full load.

The diagrams in Figs. 1 and 2, already referred to, have been selected out of a large assortment of similar diagrams relating to various conditions of service and operation because they show a comparison of the energy required for a given run with the two different kinds of motor equipments giving different accelerations. These diagrams have been prepared with the greatest care, every precaution being taken to consider, and to make due allowance for, every factor entering into the case. The data from which these curves were made were collated with the greatest care, and may be said to be substantially free from any assumption or guesswork whatever.

TABLE II.

EFFECT OF GRADES ON INITIAL ACCELERATION.

GRADE Per Cent	300 AMPERE MOTOR				400 AMPERE MOTOR			
	Speed	Acceleration			Speed	Acceleration		
	10 Seconds After Starting (M P H)	Coeff (V T)	Initial Angle		10 Seconds After Starting (M P H)	Coeff (V T)	Initial Angle	
			Deg	Min			Deg	Min
Up +2.0	10.2	1.02	45	34	17.4	1.74	60	7
" +1.5	11.3	1.13	48	30	18.4	1.84	61	29
" +1.0	12.4	1.24	51	6	19.5	1.95	62	51
" +0.5	13.5	1.35	53	29	20.6	2.06	64	7
Level 0.0	14.6	1.46	55	36	21.5	2.16	65	3
Down +0.5	15.6	1.56	57	21	22.8	2.28	66	19
" +1.0	16.7	1.67	59	6	23.8	2.38	67	13
" +1.5	17.8	1.78	60	41	24.9	2.49	68	7
" +2.0	18.9	1.89	62	7	25.9	2.59	68	53

The curves themselves were drawn on a relatively large scale, in order to enable them to be drawn more accurately and to ensure greater precision in all computations made by reference to them. In the original diagrams the speed values (m.p.h.) are drawn to a scale of 10 millimetres per mile and the time values (seconds) to a scale of 5 millimetres per second. The total chart, showing the run diagrams for all the express runs. is nearly 10 metres long and is 0.7 of a metre wide.

The curves were prepared with a view to being made as nearly expert-proof as possible. These curves constituted a part of the technical work recently submitted before the Railroad Commissioners, and the expert testimony corroborating them, as well as the manner in which they withstood the desperate attempts to discredit or criticize them on the part of the New York, New Haven & Hartford Railroad Company before the Railroad Commissioners, form, I think, a sufficient credential to entitle them to your consideration.

These diagrams and the tables will serve to make my meaning clear in regard to the various assumptions made in Dr. Hutchinson's paper, to which I have previously called attention.

Let us briefly consider the various points. As to the first point, it is well-known that no line is absolutely straight, and it is also well-known that the curves increase the resistance to traction in a manner which varies with the sharpness, or the " degree," of the curve. The increased traction resistance due to curves tends to change the slope of the speed-time curve, and, consequently, affects the form of this curve the same as an up-grade; its influence does not end here, however. The increased traction resistance is, indeed, but a secondary consideration, introduced by the railroad curve. The principal consideration is the limitation which it sets to the speed that may be safely maintained on those curves. This limitation does not operate so as to introduce any material modifications in ordinary tramcar practice, but it becomes a very serious and important consideration in rapid transit service. Unless the curve occurs at the beginning or at the end of the run, on which portions the speed is relatively low, it will be necessary to arrange matters in such a way that the speed will not exceed a certain limit at the time when the car reaches the point at which it enters the curve. This could be easily done by having a motor whose limiting speed would not exceed the safe speed for the curves; but it is unnecessary to state that this would be inadmissible, because the motor would be entirely too slow to make time on the straighter portions of the run. It is necessary, therefore, in such cases, for the car to accelerate to a relatively high speed, and for this speed to be then reduced either by coasting or braking, or both, so as to bring it down to the proper limit at the time of entering the curve. It may be necessary again to turn on the current and again accelerate, after the curve is passed, in order to maintain the schedule speed. The presence of curves, therefore, introduces what are called " notches " or " humps " in the speed-time or run-curve. These notches not only affect the form of the curve, but also have an important bearing on the energy consumption in watt-hours per ton mile. The paper of Dr. Hutchinson ignores them entirely.

One such " hump " is shown in Fig. 2, in the curve A, where the speed is reduced purposely before entering a curve of 3 degs. radius, after passing over which, the electric current is again turned on so as to accelerate the speed again for a short time before coming to the next curve, also of 3 degs., in anticipation of which the acceleration is curtailed, and some coasting is again allowed.

As for the second point, it is again well-known that there is not a railway that is absolutely level from end to end, and it is also well-known that grades materially affect the power required at different parts of the line. The principal point of interest in connection with the influence of grades in this case is the fact that a car accelerating on a grade will have its rate of acceleration modified by the grade—that is to say, the slope of the first part of the speed-time curve, or what my associate, Mr. Mailloux, designated in the Buffalo discussion as the "initial angle of acceleration," with a given equipment having a definite gearing ratio, depends upon the grade. Now, we all know that with the present resistance method of speed control the energy consumed in a given time at starting is constant, independently of the speed, up to the point at which the regulating or starting resistance is all cut out, at which point the acceleration begins to follow the so-called "motor curve." Yet the rate of acceleration, that is to say, the initial angle of acceleration, and the distance covered up to the point at which the resistance is all cut out, may differ considerably, according to the grade. This means that the speed attained within a given time and with a given energy input will depend on the grade. I have tabulated in Table I the values of the acceleration coefficient (see column headed "Coeff.), which is numerically equal to the tangent of the angle of acceleration for the eleven express runs of the proposed New York & Port Chester Railroad going in the direction of Port Chester. The highest value, 2.36 per cent., corresponding to an angle of 67° 2′, will be found in start No. 7, which, as shown in per cent. grade column, is on a down-grade of 0.9 per cent. The lowest value, corresponding to an angle of 61° 1.8′, is obtained at start No. 6, which is on an up-grade of 1.714 per cent. In starts Nos. 1 and 2, which are on a level line, the value is 2.15 (angle equals 65° 3′). Table II. gives the values of the acceleration angles and coefficients for two different kinds of motor equipments on up-grades and down-grades of 0.5 per cent., 1.0 per cent., 1.5 per cent. and 2 per cent., respectively.

It will be seen from this table that a 2 per cent. grade, for instance, changes the acceleration coefficient materially. With the 300-amp. motor the accelerating rate (coeff.) of 1.46 on the level falls down to 1.02 on an up-grade of 2 per cent. and rises to 1.89 on a down-grade of 2 per cent. With the 400-amp. motor, the accelerating coefficient which is 2.16 on the level is 1.74 on an up-grade and 2.59 on a down-grade of 2 per cent.

As to the third point, it may be said that while there is no material error in assuming constant train resistance for all cases where the speed does not exceed 25 m.p.h., yet above those speeds there is a possibility of error, which becomes a certainty when the speeds reach 40, 50 or 60 miles, the amount of error increasing with the speed. This matter is now so well understood that a mere mention is sufficient. Very little reasoning will show that the increase of train resistance as a function of the speed cannot be left out of consideration in any computations relating to high-speed service. It was shown by Mr. Armstrong, in his very able paper before this INSTITUTE in 1898, that for a given run the maximum speed reached during the run will increase as the angle of initial acceleration decreases. Now, as the train resistance is a function of the speed which is higher than the first power (usually comprised between the values of exponent = $1\frac{1}{2}$ and exponent = 2) it would follow that the energy actually consumed in the movement of the train is greater with low accelerations according to resistance values, because the maximum speeds attained and maintained during the run are higher. This is shown graphically by special curves in Fig. 2, which, for the sake of clearness, are reproduced separately in Figs. 2a and 2b. In these diagrams, Figs. 1, 2, 2a, 2b and 2c, the letter A designates, in every case, curves having reference to a 52-ton motor car equipped with four motors and using 400 amps. in each motor in starting, while the letter B designates in every case curves having reference to a 50-ton motor car equipped with four motors each using 300 amps. at starting. The curves A and B are the usual speed-time or run curves corresponding to these two kinds of equipment.

The curves I.-A and I.-B are the distance curves corresponding to these run curves—the ordinate value at any point on the distance curve, as read on the scale of miles at the right hand of the diagram, being equal to the distance traversed by the corresponding train at the corresponding time point.

The curves II.-A and II.-B are the power input curves, showing the electric power applied to each car at every instant of time during which current is used. It will be noticed that while in Fig. 1 the current is applied in each case only once, namely, at the beginning of the run, being shut off when the maximum speed has been reached, in Fig. 2 the current is again turned on for the run marked A, corresponding to the 400-amp. motor equipment. The area of these power curves is, of course, equal to the energy consumption, usually expressed in kilowatt hours.

Curves III.-A and III.-B are the energy,or kilowatt hour curves corresponding to the preceding curves and obtained by the integration of the same, the values being read by reference to the special scale (kilowatt hours) at the right-hand side of the diagram.

Curves IV.-A and IV.-B are special curves, to which we have given the name of intrinsic power curves. These curves show the power, in this case being expressed in kilowatts. These curves are calculated by reference to a simple and well-known formula expressing the relation between the speed and the power required to keep the car moving at that speed. The curves show two notches, which are due to different causes. The first, or smaller notch, is due to the increase in train resistance caused by the addition of the motor and gearing friction, which are both excluded, being counted as part of the motor efficiency while the car is running. This notch occurs at the time-point when the current is shut off. The second notch corresponds to the point at which the motor leaves the down-grade on which the start was made. The moment that the car leaves the down-grade, the energy required for traction, of course, instantly increases. In the case of an up-grade, the notch would have shown a downward slope instead of an upward slope at this point, the height of the notch being, of course, in proportion with the percentage of grade.

These curves are calculated by reference to formulæ, which include the variation of the train resistance as a function of the speed. This explains their convexity toward the time-axis at the beginning and at the end.

Curves V.-A and V.-B are the integral curves of the preceding curves, which, consequently, give at each time-point the energy consumed in train resistance up to that point. The ordinate values for the power curves are expressed in kilowatts, which may be read by the kilowatt scale at the left-hand side; the ordinate values of the energy curves V.-A and V.-B are expressed in kilowatt-hours and may be read by the energy scale at the right-hand side of the diagram.

Curves VI.-A H and VI.-B H are the corresponding intrinsic power curves, drawn according to the assumptions made in the paper of Dr. Hutchinson. These curves are calculated on the assumption that the line is level and that the train resistance is constant at 18.2 lbs. per ton, as stated in Dr. Hutchinson's paper.

Curves VII.-A H and VII.-B H are the corresponding intrinsic energy curves. These curves are reproduced separately, together with the corresponding run curves, which are exactly the same as in Fig. 2 (in Fig. 2b for the sake of greater clearness). The intrinsic power and energy curves, calculated by our own formula, are also separately reproduced in Fig. 2a. A simple glance suffices to show the radical difference between the curves shown in Fig. 2a and those shown in Fig. 2b. With the assumption of constant train resistance, the beginning and the end of the intrinsic power curves of Fig. 2b are very much higher than they should be, while they are very much lower at the middle points corresponding to the highest speeds atttained during the run.

It will be observed that while the dotted line curve (V.-A) in Fig. 2a, corresponding to the intrinsic power of the train having higher acceleration, shows higher ordinate values than the solid line curve (V.-B) in the early parts of the run, yet it shows lower values at the end of the run, the two lines crossing at a time-point about midway in the run, as clearly shown on the diagram. The total intrinsic energy is slightly under 3 k.w. hours for the higher acceleration and somewhat over 3 k.w. hours for the lower acceleration. On the other hand, the corresponding energy curves in Fig. 2b retain throughout the entire run such relation that the dotted line curve (VII.-A H) always remains above the solid line (curve VII.-B H) throughout the entire run. From the forms of the energy curves in Fig. 2a, which show clearly that the energy actually consumed in maintaining the speed is less for a high acceleration than for a low acceleration, one would be led to look for greater economy with higher acceleration; whereas, from Fig. 2b, one would be led to expect the contrary result. These curves illustrate the manner in which an unwarranted assumption may lead to erroneous conclusions.

As to the fourth point, namely, the average length of run, in the case of the New York & Port Chester Railroad, the average length of run is 1.9 miles (10,032 ft.) for the express train runs, and 0.95 mile (5,020 ft.) for the local train runs. The longest express train run is 3.114 miles and the shortest 0.689 mile. The first column in the table gives the length of all the eleven express runs in miles. It will be seen that the longest run (No. 4) is 3.114 miles and the shortest one (No. 5) is 0.689 mile. In the case of the local runs, the longest one is 1.853 miles and the shortest is 0.428 mile. It will be seen that there are not two of the express runs which are of the same length and that the range of variation is great. The same statement applies to the local runs. Referring again to the values of the factor which Dr. Hutchinson designates by the letter A and to which he gives the term "through acceleration," it will be seen that this value also varies widely, its highest value (for run No. 3) being .614 and its lowest value (for run No. 4) being .234. The variations of this quantity A are such as to show clearly that it is not an independent variable, but that it is itself a function of other things, such as the length of the run, the maximum speed attained, or of some other quantity.

In regard to the fifth point, namely, the assumption that the power will be applied during the first part of the run only, it may be said that this is somewhat related to the first, that is to say, it depends on the relative straightness of the line and has already been referred to in that connection. The necessity of reducing the speed either by coasting or braking so as to enter a sharp curve at or below a certain definite limited speed, involves in most cases the necessity of again putting on the current and of again accelerating or raising the speed before coasting. An example of this is shown in Fig. 2, in the run in curve A already referred to, where the car, after attaining a speed of 53 m.p.h., is allowed to coast, so that by the time the car enters the curve the speed has fallen to 42½ miles. The limiting speed for this curve (3° of curvature) being 50 m.p.h., the car continues to coast until the speed has fallen to 41.1 m.p.h., at which time the current is again turned on and the speed is accelerated to 45 m.p.h. The diagram shows that the energy input curve, corresponding to this second acceleration, requires an expenditure of 0.62 k.w-hours, which, added to the energy consumed in the first acceleration (6.02 k.w. hours), makes a total of 6.64 k.w. hours as the energy required for the run. In some runs it may be necessary to have three, four, or more successive accelerations. These supplemental accelerations are left out of consideration entirely in Dr. Hutchinson's paper, although they are evidently of too much importance to be thus slighted in any comprehensive solution such as this is asserted to be. The difficulty of dealing with them is increased by the fact that the percentage of energy due to these successive accelerations depends entirely upon the peculiar conditions of the case, and cannot in the present state of the art be foreseen or predetermined in any other way than by actually constructing the speed-time curve under the exact conditions. It is of interest to note in this connection that in Fig. 2, in the run corresponding to the motor having higher acceleration, the total energy consumption for the entire run is still lower than that required for the entire run with the equipment of the lower acceleration, notwithstanding the fact that, in the former case, a consequent acceleration occurs which involves an additional energy output of 0.62 k.w. hours. I have also brought with me, and will add to the discussion, four additional run diagrams (Figs. 3, 4, 5 and 6), two of which (Figs. 3 and 4) show notches due to the necessity of reducing the speed on entering curves and requiring subsequent acceleration, thus involving additional energy input. These curves give interesting information as to the expenditure of energy required for these successive accelerations. These curves and the other curves also show incidentally some interesting results of the influence which a small increase in the time of the run exerts on the energy required for this run. The table on each diagram gives the principal data and results in regard to each diagram.

As to the sixth point, namely, the use of a speed-time curve of general type for all cases and conditions, it is my opinion that such a curve, simplified as it must necessarily be, involves too many assumptions to be a safe and desirable expedient. Without analyzing very definitely the character of the correction to the type curve which the author suggests and proposes to apply, I will say that I am inclined to look upon this correction with suspicion, not only because it ignores the important points just discussed, but because of the possibility of error in the computation of the resulting energy input curve. The correction, as I understand it, consists in reducing the actual curve to an equivalent typical curve, in which the entire acceleration is along a straight line, as shown by the dotted line M A A. It seems to me that this correction leaves room for doubt as to the form of the energy input curve, and, consequently, leaves room for more or less important error in the estimated energy consumption. I surmise that this is, in fact, another one of the weak points of Dr. Hutchinson's hypothesis.

The seventh point requires no special discussion, as the discussion of the preceding points has already made its fallacy sufficiently evident.

I now come to the feature of Dr. Hutchinson's paper, which is perhaps of the greatest practical interest, namely, the somewhat radical conclusion which he arrives at, to the effect that, contrary to what has been hitherto believed, the economy of high acceleration is of secondary importance, if not negligible.

For instance, the author says: "I have made these calculations for a number of cases to correspond with practical conditions; the result is always that the energy used per mile is less for the lower accelerations." On this point I absolutely disagree with Dr. Hutchinson. The comparison already referred to between the curves in Fig. 2a and Fig. 2b is, as we have seen, opposed to this conclusion. The comparison of the energy curves in Figs. 1 and 2, in my opinion, contradicts Dr. Hutchinson's conclusion entirely. The two run-curves in each diagram, it will be noticed, are curves of equal area as well as of equal time, that is to say, the acceleration and coasting are arranged in both cases in such a manner that the run is made in the same time.

The curves show readily the necessity for higher maximum speed when using the equipment consisting of smaller (300-amp.) motors, giving a lower acceleration; and the energy input curves (3a and 3b) show a material difference in the energy consumption per ton-mile during the run, which difference is all the more striking if we take into consideration the fact that the curves (B) corresponding to the smaller motor involve a total train weight and an intrinsic energy expenditure corresponding to only 50 tons total load, while the curves (A), corresponding to the equipment of larger (400-amp.) motor, involve a total train weight of 52 tons. As would be expected, and as shown by the comparison between Figs. 1 and 2, the shorter the run (Fig. 1) the greater is the economy of high acceleration.

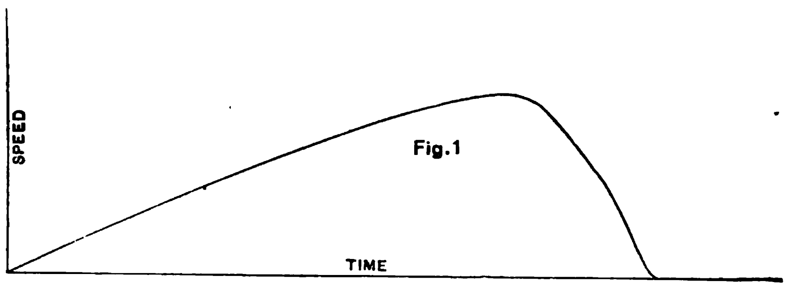
The energy required for the high acceleration run in Fig. 1, as shown by the area of the large energy diagram furthest to the left, is 4.49. The energy required for making the same run under the conditions referred to in curve B, is that shown by the energy diagram furthest to the right, and is equal to 5.32 k.w. hours. The data for both sets of conditions are given in the upper right-hand corner of the diagram.

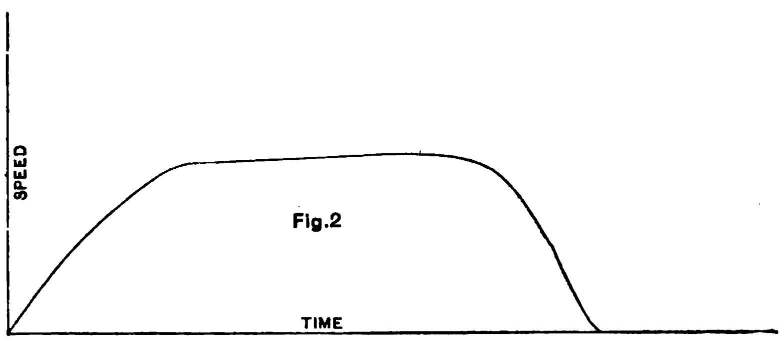
The figures for the energy input per car mile corresponding to curves A and B are, respectively, 6.52 and 7.72 k.w.hours—the corresponding figures for the energy in watt-hours per ton-mile being, respectively, 125.4 and 154.4. The increase of energy required for the lower acceleration is, therefore, 23.1 per cent. greater with the smaller equipment giving the lower acceleration. The same comparison in the case of Fig. 2 shows that the increase of energy in watt-hours per ton-mile in the case of curve B, as compared with curve A, is 18.4 per cent.

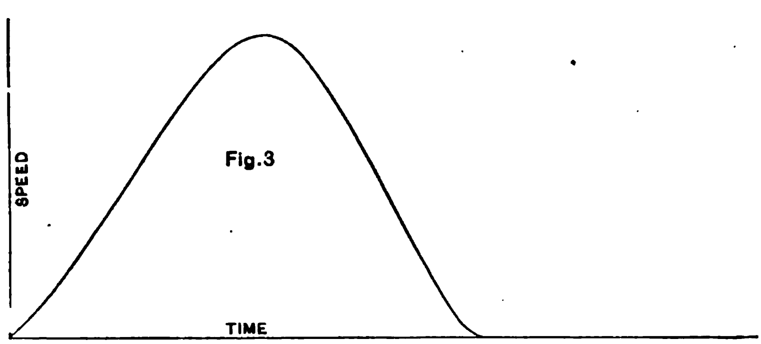
In discussing the New York Subway Rapid Transit road, the author concludes that the proposed schedule is impracticable, and he states that a motor capacity of 14.9 k.w. per ton is beyond the range of practical conditions. As the conditions in the case of the New York & Port Chester Railroad express service are, if anything, more severe, owing to the higher schedule speed, it would seem that the practicability of this project would also fail to meet the requirements of Dr. Hutchinson's formulas. The 52-ton car has an equipment of four 400-amp. motors, operating at 600 volts, making an input of 960 k.w., or about 18.5 k.w. per ton. If there should be a discrepancy between what we have found to be possible and what the hypothesis presented in this paper admits or limits, I, for one, think that the adjustment necessary to bring the two into harmony will have to come largely, in fact one might say wholly, from the side of theory.

MR. M. H. GERRY, JR., [*Communicated*]:—The paper by Dr. Hutchinson contains a very interesting and able theoretical discussion of certain problems in connection with moving trains by electricity. While any general discussion on this subject is of great value, it does not seem that this paper embraces a sufficient number of the operating conditions to justify such general conclusions as stated by the author. In fact, it is highly improbable that any complete mathematical discussion can be had which will give correct general conclusions on these points. The conditions of practical railroading are so varied, and the results to be obtained depend to such an extent upon the traffic arrangements, that it is almost essential that each particular case be considered by itself. On certain elevated and suburban roads, the question of schedule speed is of first importance, as on it depends the amount of traffic which can be handled, and hence the amount of income received. In a case of this kind it is not a question of power, but rather one of maximum schedule speed which can be regularly and safely maintained, with stations at certain fixed distances apart; and the more rapid acceleration obtainable is usually the most desirable, for the reason that the fastest schedule can be obtained by the highest rate of accelerating, up to the point of applying the brakes, and then retarding as rapidly as possible, until the train is at rest.

As far as train efficiency is concerned, it is of course, well-known that the least energy will be required with the highest acceleration up to a point at which the power is cut off and the train allowed to coast until such a speed is reached that the brakes, by causing the maximum retardation, will just bring the train to rest at the proper point. Such theoretical conditions are, however, rarely either the most economical or the most desirable ones in practice. As a usual thing, certain distances between stations, maximum speed, number of trains, amount of traffic, etc., are determined by conditions entirely outside of those of power, and it then becomes the problem to operate a train service as economically as posisble. The curve (Fig. 1), from a power standpoint, represents conditions about as poor as it is possible to obtain, but nevertheless it was the best obtainable with certain steam locomotives on a suburban division. If it had been possible to accelerate more rapidly and then either coast or maintain a nearly constant speed until the point of applying the brakes was reached, a great saving might have been effected; but owing to the motive power and traffic conditions, the particular curve shown was the best that could be obtained. On many surface roads, and especially on street railways, the maximum speed is the limiting factor. In a case of this kind it would be the best practice to make use of a moderately rapid acceleration, up to approximately the maximum speed allowed, and then to maintain this speed until it became necessary to







apply the brakes in order to make the required stop. This would produce a flat-topped curve something like Fig. 2, and while not representing the most economical conditions from a power standpoint, it would still represent the most desirable practical conditions, as it would produce the highest schedule speed, keeping within the limits of maximum speed, and with the smallest consumption of energy, under these conditions. Where maximum schedule speed is of the first importance, and there are no limitations as to maximum speed, then of course, it is merely a problem of accelerating as rapidly as possible, up to the point of applying the brakes; thus producing a speed-curve like Fig. 3.

The energy required to move a train between two points given is made up of three parts First, that due to the grade, or the amount required actually to lift the train, regardless of speed; second, the energy to overcome train resistance, *i. e.*, friction; third, the energy required to bring the mass of the train to a certain velocity, *i. e.*, the kinetic energy, which is afterward wasted by the brakes, this energy varying approximately as the square of the speed at the time the brakes are applied. In some cases the kinetic energy is a very large percentage of the total, this occurring where the distance between stations is short and the velocity relatively high. On the other hand, where the stops are infrequent, the stations being at long distances apart, and the velocities comparatively low, then the kinetic energy at the time the brakes are applied is comparatively a small percentage of the total energy required; the greater part of which is due to overcoming train resistance and grades. In a case of this kind there is no necessity for rapid acceleration. In fact, there is no general rule which can be made to apply to all conditions of railroading in this respect.

The author makes certain deductions based on the common one-hour rating of railway motors which are hardly in accord with the results of practice in the use of such motors. There is an important distinction between the power which a motor will develop at any particular instant and the average load which it will carry on an all-day basis. As a matter of fact, the one-hour rating has only a slight relation to either the maximum or the average load, but has been adopted by the manufacturers as a fair test for heating, by which different motors may be compared. As far as commutation goes, any modern railway motor will produce power for short intervals of time very greatly in excess of its rating; in fact, this is one of the chief advantages of electric motors for this purpose. The conclusion of the author that the motor capacity must be increased in proportion to the power required during the time that the train is accelerating, is hardly correct. The motor capacity required is more nearly proportional to the work done than to the power, and hence it does not follow that an increased acceleration necessarily means an increased motor capacity. The final conclusion of the author of this paper that the lowest acceleration is best under practical conditions is not in accordance with either the experience or the deduction of most engineers who have had under consideration problems of this kind. Furthermore, the conclusion that the single advantage for rapid acceleration is the saving in energy is hardly borne out by practice, where often the more rapid schedule speed obtained is of even greater importance than the saving of energy. Then, too, it cannot be admitted that the investment is necessarily greater, that there is an increased cost of maintenance, or that the station load factor is poorer, with increased acceleration of the trains. These conditions may, or may not hold, depending more upon the design, the system adopted, and the ends to be obtained, than upon the mere fact that the train acceleration is either increased or decreased in any degree. It is desirable, of course, to avoid extremes and keep within practical limitations, and in doing this it may be safely said that there is no fixed rule, but that each particular case must receive special treatment.

The conclusions of this paper I believe to be entirely too general and to be misleading, as applying to certain classes of railroading.

PRESIDENT STEINMETZ:—The previously announced discussion is here finished and discussion is open to all who desire to make any further remarks.

DR. HUTCHINSON:—I should like to make some statements at this point.

PRESIDENT STEINMETZ:—Considering the character of the paper and of the discussion, I would like you to understand that we do not relieve you from further discussion by the remarks that you may make here, but expect that when you have seen in print the remarks of the different speakers, you will favor us with a complete answer, after fully considering all that has been brought up here in the discussion, the more as it appears to me that the scope of the paper, as a general and not a special investigation, has been somewhat overlooked in some of the discussion. The general discussion is now opened.

MR. PHILIPPO TORCHIO:—Dr. Hutchinson has presented a very interesting and able paper, clearly stating the different factors entering into the problem of determining the most economical results for traction in cities. However, the most economical results are not always the most desirable in practice. It is a proved fact, known for several years, that the high acceleration at starting gives increased economy. On the other hand, under the practical conditions prevailing in the operation of surface lines in large cities, the advantages of high acceleration cannot always be obtained, as the motorman will not, as Mr. Potter has pointed out, start with the high acceleration, shut off the current at the proper point, then take a long coast and make a short brake at the end; but usually he will keep on the current most of the time until he is signalled to stop and then he will brake abruptly. Under practical tests made by railroad engineers on several lines, it was proved that the 23 per cent. increase of economy at a high acceleration, given by the speaker of the evening, under practical running conditions, was reversed to 6 per cent. increased energy consumption. The comparative test was made, using motors of about 50 per cent. larger capacity than were used before, the running schedule and other things being maintained equal. However, practical considerations other than that of the saving of energy, led these engineers to adopt the larger capacity motors in place of the motors most economical as to energy consumption, station capacity and copper investment.

MR. H. G. STOTT:—I think, as a first proposition, it is thoroughly recognized by all railroad men that maximum acceleration gives maximum economy. A number of points have been brought out, but that one, it seems to me, is the principal one that everybody has to recognize. Another point brought up has been the question of stored energy in the motors. Some time ago I saw some investigations carried out on that subject, and while theoretically it developed that there was a distinct loss of energy due to fly-wheel effect, or stored energy in the motor, yet in an actual test, under working conditions, these results were not corroborated and the practical test with ten-second readings of instruments, did not show that the results of the calculations were corroborated. There are a great number of points to be considered. For instance, looking at the speed-time curves, the stored energy may be recovered by cutting off a little sooner and coasting, and in that way it might be a positive benefit to have a larger armature and therefore store more energy; and that subject, I think, would be a very good topic for a complete discussion for an entire evening, because there are so many different phases of the question. But that is one practical result that we get in investigating it, that the theoretical calculations were not borne out. In looking over Dr. Hutchinson's paper I must agree with the rest of the critics in saying that I do not quite see where it applies to existing railway conditions.

PRESIDENT STEINMETZ:—Dr. Hutchinson's paper considers the operation on a level, straight track, with equidistant stops. Those are not the usual railway conditions. I agree as to that. But so is the standard test of an alternator on non-inductive load, not representing operative conditions, but the operative conditions will infinitely vary. You may have all kinds of load, but you must have some definite standard from which, by knowing the particular conditions of your case, you can by judgment derive the results. This, for the alternator, is non-inductive load, although very few alternators in commercial service will enjoy a non-inductive load. So here, from the performance of the railway motor on a straight, level track, with equidistant stops, we may by knowing the particular severity of our service as regards curves and grades derive by judgment what the motor will do in actual service. We may be mistaken in our judgment, but surely we are very much nearer than if we knew nothing at all. If we know exactly the conditions, the profile of the road, the curves and grades, the character of the motorman who is going to operate the car, etc., then we can get very much more accurate results, undoubtedly, but where we do not know the actual conditions, we are permitted by judgment to reach a conclusion regarding the behavior of the motor more accurate than by the former guessing. That, I understand, is the purpose of the paper.

Before we adjourn I may say that it is proposed to have at the Annual Convention one meeting devoted to the electric railway, as it is a very important matter, so whatever some of you may remember afterwards as very interesting for discussion here, we can discuss at that time,

MR. S. T. DODD:—I wish to express my appreciation of the method and results of this paper. Many of us have spent a good deal of time juggling with motor curves and working out results for particular cases. General formulas of universal applicability for determining the distance transversed, the energy expended, the speed, etc., for problems in motor acceleration have been needed for a long time and if, as appears from this paper, the writer has developed such formulas of convenient and general application, he has made a decided advance in the study of such problems. I do not feel sufficiently familiar with the paper to criticize its general results or to say how convenient the formulas may be for every day use, but it appears that the results should be of great assistance to us.

Some time ago, I spent a good deal of time on the investigation of some problems in acceleration, and in view of the results arrived at in that investigation, I have been particularly interested in the conclusion of this paper, namely, that the lowest acceleration possible under " practical conditions " is the best. It appears to me that there is a possibility here of a very interesting general investigation to carry this conclusion further and to determine what are the practical conditions under which one or another acceleration is advisable.

This thought has led me to take up again my old problem and apply to it the formulas of Dr. Hutchinson's paper and if my results differ from his, it is to be attributed to the assumptions that I have made in my particular case and to the fact that I have developed my investigations along slightly different lines from his, or perhaps to the fact that I have not appreciated the limitations of his formulas and curves.

Let us consider a car equipped with motors of such a capacity as to give it an acceleration of 2 m.p.h. per second, up to 15 m.p.h. at rated load of the motors. This is an acceleration which is ordinary, or at least, is frequently met with in practical conditions.

We will assume that during acceleration, we do not exceed the rated load of the motors, *i. e.*. while cutting out resistance, we work along the line $a = 2$ at the point 100—100 of curve sheet 5 and that at the point where all resistance is cut out, the speed, β 100 = 15, therefore β = .15. Assume, moreover, that b, the

TABLE A.

$a = 2$ $\beta = 15.$ $L = 1500'$

Time Seconds	Speed m.p.h.	Distance Feet	Energy w.h.	Schedule Speed m.p.h.	W.h. per ton mile.
7.5	15.	82.5	11.75		
12.	19.5	195.	17.4	10.05	61.7
16.5	21.6	330.	21.3	12.36	75.
21.	22.8	472.	24.4	13.16	86.
25.5	23.8	622.	27.1	13.65	95.5
30.	24.7	792.	30.	14.02	105.
34.5	25.35	982.5	32.45	14.28	114.2

TABLE B.

$a = 1$ $\beta = .227$ $L = 1500'$

Time Second	Speed m p h.	Distance Feet	Energy w.h.	Schedule Speed m..h.	W.h. per ton mile.
27.7	27.7	565	43.6	13.05	153.5
31.85	31.	756	50.9	14.	179.
36.	33.	947	55.9	14.15	196.7

TABLE C.

$a = 3$ $\beta = ..103$ $L = 1500'$

Time Seconds	Speed m.p.h.	Distance Feet	Energy w.h.	Schedule Speed.	W.h. per ton mile.
3.44	10.3	26	5.38		
15.80	17.92	281	14.6	8.48	50.7
17.86	18.5	334	15.66	10.27	55.1
19.92	19.	392	16.71	11.1	58.8

negative acceleration during coasting, equals .2, or the train resistance is equal to 18.2 lbs. per ton. Apply now formula (18) the power developed per ton by this equipment is $P = .182 (a+b)\ ax = 6$ k.w. or 8 h.p. This would correspond for example, to a 15-ton car equipped with two 60 h.p. motors. We will assume that this equipment is making a run with a distance of 1,500 feet between stations. The energy expended, distance

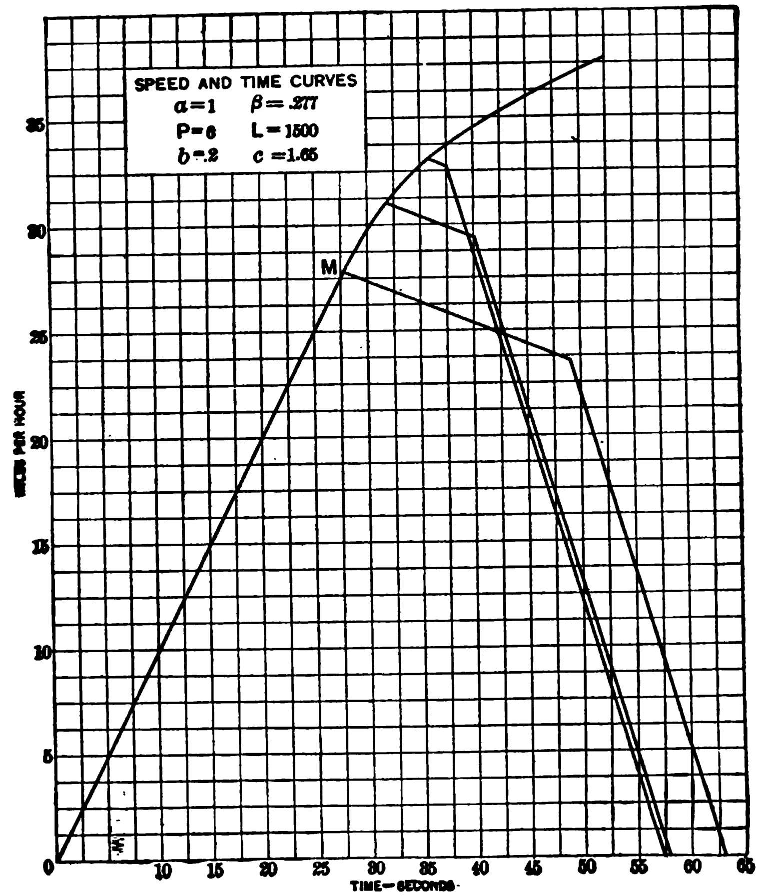


Fig. 1.

traversed and speed of the equipment may be determined directly from curve sheet 7. Now, the question I wish to investigate is: Suppose the same equipment was geared for a higher or lower speed, but was started in every case at its rated load, what would be the effect of this change of gearing on energy consumption, schedule speed, etc.

($a = 2$). We will study first the case where the car is geared for an acceleration $a = 2$ at its rated load. The results can be derived from curve sheet 7 and are tabulated in Table A. The first row of figures in this table corresponds to the time up to the point M on the speed curves, where all the resistance is cut out The succeeding rows correspond to the values 30, 60, 90, etc., of x on curve sheet 7.

The first column gives the time elapsed since the starting, and is derived by multiplying each value of x by β and adding the result to the initial value of t (7.5 sec.) given at the top of the column.

The second column gives the speed, read from the velocity curve.

The third column gives the distance traversed, read from the distance curve and added to the initial value of distance 3,670 β or $82\frac{1}{2}$ feet.

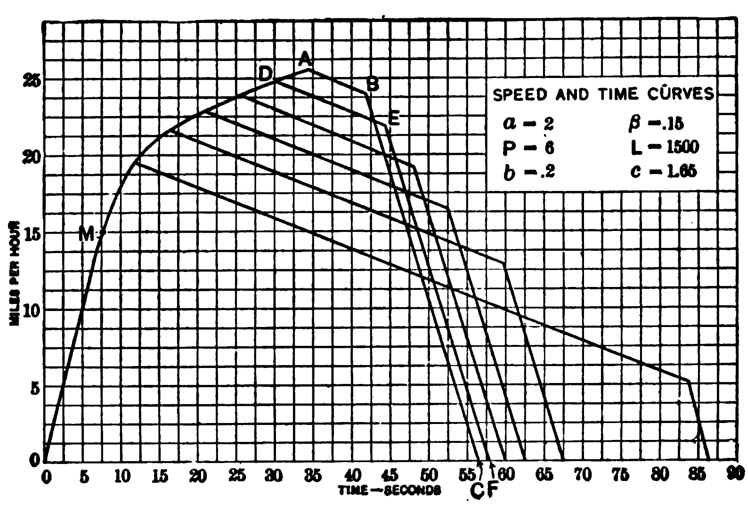


Fig. 2.

The fourth column gives the energy expended, read from the energy curve and added to the initial value 522 β or 11.75 watt hours.

Now let us assume that the power is shut off at any one of these points and the car is allowed to " coast " and finally braked and brought to rest at a distance of 1,500 feet from the starting point. We will assume the frictional retardation (b) is .2, corresponding to 18.2 pounds per ton and the braking retardation (c) is 1.65, corresponding to 150 pounds per ton. Knowing from Table A the velocity V and the distance to be traversed during coasting and braking ($1,500 - d$), we can find y, the time during which the car will coast and z, the time during which it will be under braking retardation.

The formulas connecting these two quantities are as follows:

$$b\,y^2 + c\,z^2 + 2\,b\,y\,z = 2\,(1500 - d)\,.682$$

$$b\,y + c\,z = V$$

$$\therefore z^2 = \frac{V^2 - 1.364\,(1500 - d)\,b}{c\,(c - b)}$$

$$y = \frac{V - c\,z}{b}$$

The values of V and d from Table A, substituted in the first of these equations gives the time z during which braking will take place. Values of V and d such that V^2 is less than 1.364 $(1{,}500 - d)\,b$, give imaginary values of z; *i. e.*, indicate that the car

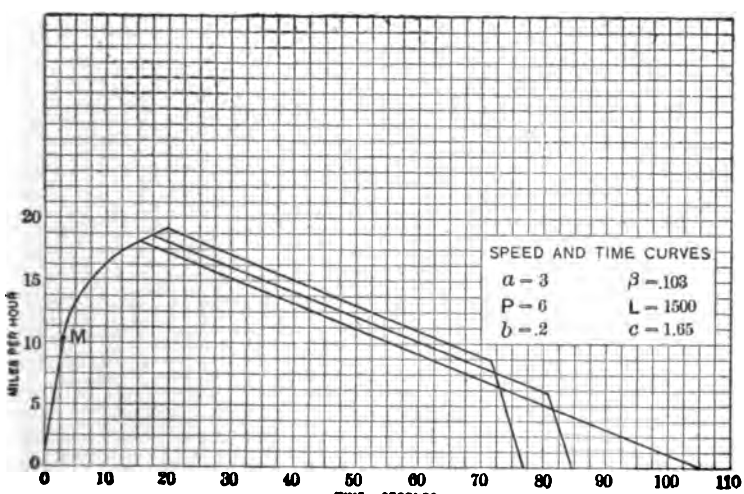


Fig. 3.

if allowed to coast from such a velocity, will stop from frictional resistance before traversing 1,500 feet. Values for which V is less than cz indicate that the car, even if braked with "no coasting" would have traversed over 1,500 feet before being stopped.

Let us first assume the power shut off at the time $t = 34\frac{1}{2}$ sec. Applying the formulas for y and z we find the car will coast 7.5 seconds (y) and be brought to rest under the brakes in an additional 14.45 seconds (z). The relative amounts of acceleration, coasting and braking are most satisfactorily shown in the "speed-time curves" for $a = 2$, by the curve O, M, A, B, C. The intercept on the base line shows that the total time the car has been in motion is 56.45 sec. Adding to this 15 sec. for the stop at the station, we get the schedule time for a run of 1,500 feet, from which the schedule speed 14.28 m.p.h. may be calculated. If the power is shut off at the time $t = 30$, the coasting curve is longer

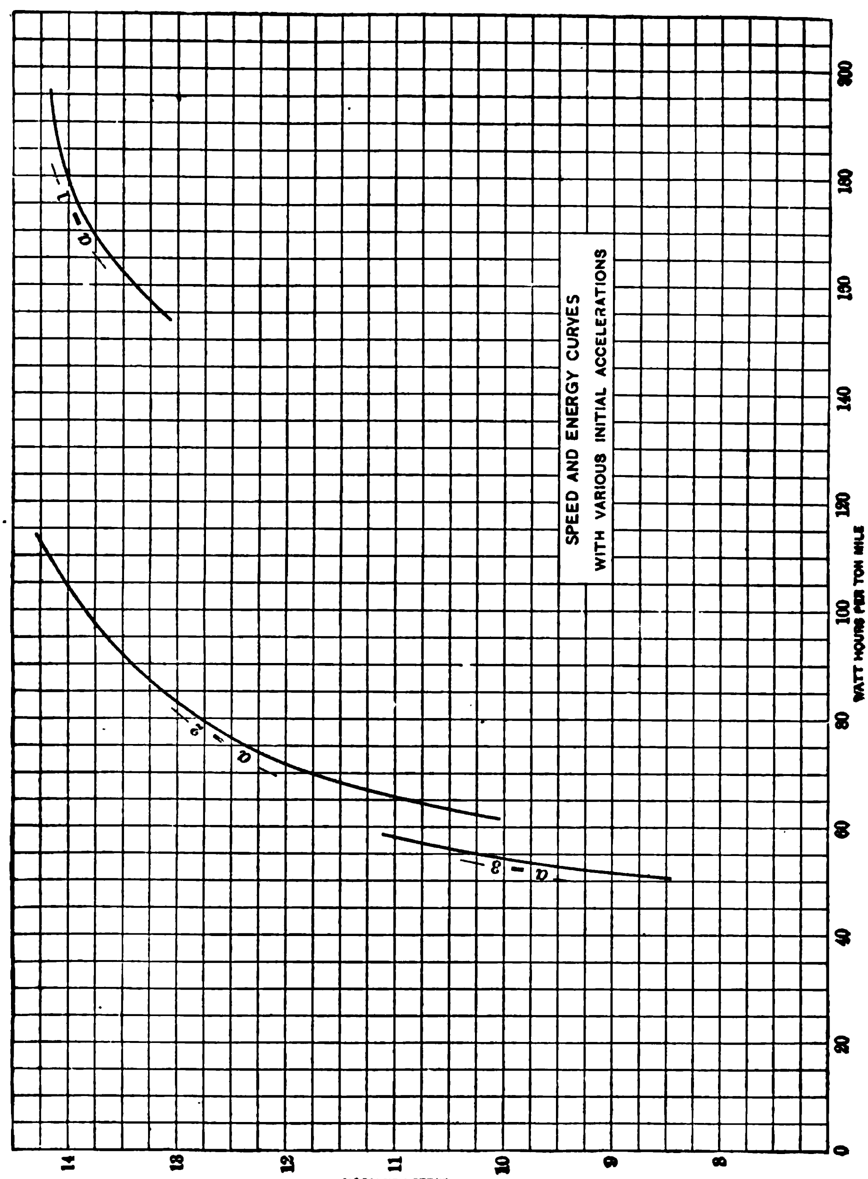

SPEED AND ENERGY CURVES
WITH VARIOUS INITIAL ACCELERATIONS
a = 1
a = 2
a = 3
WATT HOURS PER TON MILE
0
20
40
60
80
100
120
140
160
180
200
MILES PER HOUR
14
13
12
11
10
9
8

Fig. 4.

and consequently the schedule speed is less. This is shown by the curve O, M, D, E, F, of the same sheet.

The successive straight lines starting from the acceleration curve on this sheet show the effect of shutting off power and beginning coasting at the successive times shown in Table A and the schedule speed, calculated from the intercepts on the base line are tabulated in the fifth column of that table.

Values of V and d at the time $t = 7.5$ give imaginary values of z showing that the car would not cover 1,500 feet if allowed to drift from this point.

As said above, the fourth column of Table A gives the energy expended per ton up to the time under consideration. If the power is shut off at this point, this represents the total energy used in traversing 1,500 feet; multiplying this by 3.52 gives the energy expended per ton for traversing one mile. The sixth column of Table I gives the watt hours per ton mile thus calculated.

($a = 1$). Let us now assume this equipment geared for a higher speed and lower horizontal effort, so that at its rated load it will develop an acceleration $a = 1$. Since the horse power of the equipment is the same as before, we have from formula (18)

$$P = .182\,(a+b)\,ax$$
$$6 = .182\,(1.2)\,\beta\,100$$
$$\beta = .277$$

The results of this are tabulated in Table B and illustrated in the "speed-time curves" for $a = 1$. The values in the Table B are derived from curve-sheet 8, as those in Table A were from curve-sheet 7. It will be seen that only a few readings are possible, as beyond $t = 33$ sec. we get negative values of y. The "speed-time curves" show that this means that nearly all the time is spent in acceleration up to the motor curve and in braking down from it.

($a = 3$). Let us now assume the equipment geared for a low speed and high horizontal effort, so that at its rated load it will give an acceleration $a = 3$. Again from equation (18) we derive the value of $\beta = 1.03$, and from curve-sheet 6 we derive the values of distance, energy, etc., shown in Table C. Here again, we are limited to only a few readings, as those below $t = 15.8$ seconds give imaginary values of z, showing that the car would not run 1,500 feet if power was shut off below this point. I have not attempted to carry the curves much beyond the points shown on curve-sheet 6. It would be interesting to study the results in this case beyond this point, but the readings we have, are sufficient to show the character and relations of the curves.

We are now in a position to answer the question we started to investigate, as to the relative amounts of energy used by operating with different accelerations. We have the data in the fifth and sixth column of each table from which to plot the relation between schedule speed and energy expended for the different rates of acceleration. This has been done on the sheet of "Energy and Speed Curves." The curves on this sheet show for any given initial acceleration the effect on the energy consumption of introducing more or less coasting in operation and thereby modifying the schedule speed. Two or three points are worth noting in these curves.

(*a*). The watt hours per ton mile vary from about 50 to 200 according to the character of the acceleration and amount of the drifting.

(*b*). The energy is a minimum at the "no braking" point which is the minimum speed and increases with the speed, slowly at first, but quite sharply as we approach the "no coasting" point. This is to be expected, as the higher values represent greater losses in brake friction.

(*c*). The $a = 2$ curve is shown throughout nearly its whole length from the "no braking" point to the "no coasting" point.

The $a = 1$ curve is shown from the beginning of the motor curve to the "no coasting" point.

The $a = 3$ curve is shown only a short distance up from the "no braking" point. It would be interesting to carry the curve further and see its character at higher schedule speed.

(*d*). Comparing the $a = 1$ curve and the $a = 2$ curve it appears that the average watts expended per ton mile with an initial acceleration $a = 1$ is nearly 100 per cent. greater than the watts expended with an initial acceleration of $a = 2$, with the same starting currents and the same schedule speeds.

The $a = 2$ curve shows an expenditure of energy about 10 per cent. greater than the $a = 3$ curve for the same schedule speeds.

Whether these curves would continue to be approximately parallel to each other, or whether as the $a = 3$ curve approached the "no coasting" point it would cross the $a = 2$ curve, can only be determined by carrying the curves of curve sheet 6 to higher values. It is evident from an inspection of the "speed time curves" for the two cases that it would not be possible to attain the same maximum schedule speeds with the $a = 3$ curve as with the $a = 2$ curve.

The conclusion which this investigation appears to indicate is that in this particular case the higher acceleration is the most economical not only in the power-house, but on equipment. You will note that we have assumed in every case that we have the same equipment and it is started with the same starting current, but in one case is geared for a high speed and in the other for a low speed, and the curves show that at the same schedule speeds, the average power consumption is less for the higher rate of acceleration.

As I understand Dr. Hutchinson's paper, his general conclusions are directly opposed to this, at which I have arrived. He is more familiar than I am with the methods and reasoning of his paper and may be able to point out the difference in our assumptions or reasoning which has led to this apparent discrepancy. I started to follow out this investigation with the intention of testing the convenience of working from his formulas and curves and trust that the results are of sufficient interest to warrant me in contributing them to this discussion.

MR. P. O. KEILHOLTZ [*Communicated*]:—Dr. Hutchinson is to be congratulated upon his very clever analysis of the problem, but I am of the opinion that the solution is largely academic and I do not agree as to his conclusions. I consider that the most important railway engineering problem is that of increasing the capacity of the road with the view of increasing its gross revenue. This means decreased running time, and with frequent stops, the time of acceleration is a most important factor. It also means increased station, terminal and yard facilities, greater power and transmission capacity. Decreased running time requires better signaling systems, better roadbed, etc. In fact, the capacity of a road is a function of its total cost to which its power and transmission plant may bear a very small relation. It therefore follows that the problem of acceleration of trains by electric traction should be considered in relation to the total cost of the road and its cost of operation, rather than in its relation to an item of that cost and operation.

DR. LOUIS DUNCAN [*Communicated*]:—Dr. Hutchinson's paper is valuable, as it brings out clearly the fact that a maximum train acceleration does not always mean an increased economy. The factors which he has taken into account have been neglected in the ordinary treatment of the subject. A high acceleration means an increased weight, and the added weight makes the energy per car mile for the same schedule about the same for all accelerations within the limits imposed. The tests which have been published, showing increased efficiency for high accelerations, have been made on trains with constant weights and with the same motors. They are not applicable to the practical case in which the motors must be designed to fit the acceleration.

It should be distinctly understood that in the paper the schedule is fixed, and the question discussed is the best acceleration to make this schedule. The motor curves are apparently taken from actual results obtained from machines now on the market and in operation, so there should be no question of their approximate accuracy.

The paper is important because it has lifted the question of train acceleration out of a rut and put it on a level of commonsense engineering.

[COMMUNICATED AFTER ADJOURNMENT BY DR. HUTCHINSON IN REPLY TO DISCUSSION AND CORRESPONDENCE.]

This discussion shows such serious misunderstanding of the paper that I will state its scope before referring to the remarks in detail. One of the most important factors in considering train movement is the initial acceleration. My purpose is to show the effect on the energy and motor capacity of using different initial accelerations. To this end it is necessary to keep all other conditions constant, otherwise the result is due to a change in more than one condition and cannot be estimated accurately.

I have therefore elaborated a method that gives the effect of varying the initial acceleration on the energy and motor capacity required for any fixed schedule speed over any distance. That is, I discuss the results of making, *e. g.*, a schedule speed of 15 m.p.h. for a distance of 2,000 feet, with any assumed initial acceleration. I do not discuss the differences due to various schedule speeds, although this is a simple deduction from the data given. Nearly every participant in this discussion has missed this point, and has assumed that the discussion was on the relative value of high and low schedule speeds.

To bring out the effect of varying one quantity all others must be kept constant. It is therefore necessary to use a generalized motor curve applicable to all sizes of motor. The general curve that I give is the average from a number of tramway motors now made by the two chief companies.

The criticism that these curves are not applicable by reason of the varying values of the motor losses is clearly without foundation; different motor characteristics will effect similar changes for any initial acceleration; better absolute results will be had with a better motor, worse with a poorer, but the relative results will not be altered.

The paper is based on certain assumptions; one is that the motor carries only the "rated current" during the period of initial acceleration. I have deduced the curves on various other assumptions of load during the initial acceleration up to 50 per cent., overload. The relative results are not changed materially thereby, although the motor capacity required is changed. These curve sheets were not published; they would have made the paper too voluminous.

Perhaps the best answer to the general criticism of the "theoretical" and "mathematical" nature of this paper is a comparison of the results given by these curves with results obtained independently.

In the issue of the *Electrical World* of Jan. 25, 1902, the following data are given of the equipment adopted by the engineers of the Manhattan Elevated Railway after long investigation:

Schedule speed, 14.7 m.p.h.
Length of run, 1,775 ft.
Station stop, 14 secs.
Running time, 68 secs.
Total time, 82 secs.
Initial acceleration, 1.5 m.p.h. per second.
Retardation after braking, 2 m.p.h. per second.
Energy used per ton mile, 77 watt-hours.
Train weight (equivalent) 174 tons.
Equipment adopted, 8 G. E.-66, 1000 rated h.p.

Kilowatts per ton, 4.3.
Starting current per motor, 200 amps,
Load at starting, 100 per cent. of rated capacity.

From these data, the average velocity $V = 17.7$ m.p.h., and the through acceleration $A = .26$.

The rule given in the paper is: The best initial acceleration to adopt is that acceleration giving the minimum motor capacity. Since these motors are used at their rated capacity during initial acceleration, as is assumed in the paper, the curve sheets are applicable except in so far as they are modified by the fact that the braking retardation adopted is 2 m.p.h. per sec. instead of 3, as used in the paper. This will make a very slight difference in the results.

Curve sheet 14, for $A = .26$, gives for the initial acceleration for the minimum motor capacity 1.5 m.p.h. per sec., agreeing exactly with the figures determined by the Manhattan's engineers. Curve sheet 13, at this initial acceleration, gives for the energy required 75 watt-hours per ton mile. The Manhattan's engineers find 77; the agreement is substantially perfect.

Again, from curve sheet 14, the motor capacity required is

$$.165 \times (1775)^{1/2} = 6.8 \text{ k.w. per ton.}$$

The capacity adopted by the Manhattan's engineers is 4.3 k.w. per ton. This difference is material. An examination of the curve sheets of the motor adopted—the G. E.-66—shows at once the reason. In the paper it is assumed that the sum of the core and copper losses at rated load is 12 per cent. of the rated capacity. Curve sheet 14 is based on this assumption, which, as I have said before, is a fair assumption. It happens, however, that this particular motor has a very low heat loss, the sum of the copper and core losses being only 7.8 per cent. at rated load. The motor capacity depends directly upon this loss. Reducing the capacity found from curve sheet 14 in the ratio of 7.8:12—that is, the ratio of the heat losses at rated load—gives a motor capacity of 4.42 k.w. per ton for a motor such as the G. E.-66. This figure is practically identical with the value adopted for the Manhattan equipment.

In other words, the engineers of the Manhattan Railway have unconsciously followed the rule contained in this paper and have adopted, after laborious investigation, motors giving exactly the same initial acceleration and the same energy consumption as would have been determined in a few moments by the curve sheets of my paper had they been available; and when proper allowance is made for the difference in the heat losses, practically the same motor capacity per ton. The engineers of the Manhattan Company evidently do not believe in high initial accelerations.

There is little that requires a detailed reply in the discussion of the paper. Mr. Stott and Mr. Gerry both state that it is a "recognized fact" that maximum accelerations give maximum economy. This, of course, I dispute; and as they offer no testimony to support their position, it must be taken merely as a matter of opinion. Mr. Gerry and others confuse schedule speed with initial acceleration and seem to think that I am arguing for low-schedule speeds.

Mr. Potter's paper gives interesting data on the individual characteristics of different motors, but has no particular bearing on my paper. We all know that motors differ, and for this very reason it was necessary for me to assume an average motor. Mr. Potter has probably not attempted to test the application of these curves to practical conditions, or he would not have stated his belief that they were not applicable.

Mr. Gotshall has presented a number of interesting curves showing the "runs" on his proposed New York & Port Chester road. These curves are merely paper estimates, made in the same general manner as some of my curves are made, but for specific motors. By adding a discussion of the effect of grades and curves (which I purposely omitted, since they are arbitrary), Mr. Gotshall attempts to show that the results of my paper are not applicable to practical conditions. He finds great difficulty in comprehending the meaning of the quantity "A," the "through acceleration"; in fact, I think that it would hardly be an exaggeration to say that he has not yet comprehended it. In the verbal discussion of the paper he announced his discovery that this quantity A, which he declared I had called *constant*, had very different values for the different runs of his road. After thinking the matter over he offers in the written discussion another interpretation in these words: "In his paper Dr. Hutchinson has used and applied the letter A as a symbol designating what he chooses to call 'through acceleration,' which is a purely abstract idea, the physical meaning of which is not easy to realize. . . . The variations for the individual runs in the values of this quantity are very great, the differences being as much as 200 per cent. I believe that Dr. Hutchinson intends the value of A to be a sort of average acceleration factor."

I think it is hardly necessary to comment upon these quotations.

Mr. Gotshall, again referring to my unfortunate quantity A, shows that he finds great difficulty in grasping the meaning of "independent variable." He says: "Referring again to the values of the factor which Dr. Hutchinson designates by the letter 'A,' and to which he gives the name 'through acceleration,' it will be seen that this value also varies widely, its highest value (for run No. 3) being .614 and its lowest value (for run No. 4) being .234. *The variations of this quantity A are such as to show clearly that it is not an independent variable, but that it is itself a function of other things, such as the length of run, the maximum speed attained, or of some other quantity.*" Possibly he means by "some other quantity" that it is a function of the understanding of the reader, or the want thereof.

Mr. Gotshall also seems to think that he can use such motor capacities as 18.5 k.w. per ton. Since the weight of motors, controllers, brakes and sundry electrical equipment is very approximately 70 lbs. per k.w., this means that 1,300 lbs. will be required for these parts alone. It is difficult to see how the remaining 700 lbs. is sufficient for trucks, car body and passengers. That no such motor equipments will ever be used is a safe prediction.

Mr. Dodd, in his discussion, has taken the data and formulæ of my paper and by handling them in an incorrect manner has deduced certain results which are directly opposite to my results. He starts with equation (18) of the paper and makes it an arbitrary substitution of $100 = a\,x$; using the resulting equation, he calculates three tables. For each of these tables the initial acceleration, the brake power and the distance are constant. By assuming more or less use of the motor curve he gets several schedule speeds, and from them calculates the energy consumption. He then plots the schedule speeds so obtained in terms of energy consumption for the three different initial accelerations. This final curve sheet, which is the summation of his paper, offers no basis for comparing the same schedule speed with different initial accelerations. All that it does show is the difference in energy required for more or less use of the motor curve, with constant power, for the three particular initial accelerations assumed. In Table A. for instance, a schedule speed of 14.02 m.p.h. is obtained, with a velocity of 165 per cent. of the rated velocity; whereas in Table B the schedule speed of 14 m.p.h. is obtained with a velocity of 112 per cent. of the rated velocity. These two values are not comparable, as they are obtained under entirely different conditions.

In addition, Mr. Dodd uses the wrong equation to calculate the input. If any equation of this character is to be used, the equation (23) is the correct one and not (18).

The misunderstanding of the purport of the paper shown in the greater part of the discussion is in striking contrast to the clear view of its scope shown by our President. His statement of its bearing on the general question could not have been improved upon.

[COMMUNICATED AFTER ADJOURNMENT BY MR. S. T. DODD.]

I had not intended to participate further in the discussion of Dr. Hutchinson's paper, but some of the statements in his revised reply to my original discussion demand a little further attention. Dr. Hutchinson agrees that I have "deduced results which are directly opposite to" his results, and as in his endeavors to explain that fact he falls back on the plea that I have handled his data and formulæ in an "incorrect manner," I wish to reply to his criticism.

His first criticism is that I have made an "arbitrary substitution of $\beta\,100 = ax$." I reply that this substitution is perfectly justified by the definitions of his paper and by the data of my problem. From curve sheet 5 of the paper, the speed at full load is determined by the point $X = 100$, $Y = 100$, and by the equation " Velocity $= Y$ in m.p.h." Therefore, on my assumptions, for the case $a = 2$, $100 = 15$ or $\beta = .15$. In obtaining a value for β in the other cases, I make use of equation (18). The equation in question is

$$P = 0.182\ (a+b)\ ax\ kw \qquad (18)$$

Where according to the definitions of the paper,

P = power per ton developed at the car axle.

a = initial acceleration.

b = coasting retardation.

x = time, in seconds during which the acceleration " a " has been acting.

ax = velocity in miles per hour at the end of the time x.

In getting an expression for the power developed by the motors at their full load, I assume x is the time necessary to accelerate the load up to full load speed of the motors, *i. e.*, up to the instant when the rheostat is cut out and the motors begin to work on the motor curve. Therefore, ax is the full load speed of the motors, or 15 m.p.h. The equation " $\beta\ 100 = ax$ " is not true as a general equation, and I have not used it as such; but at the instant under consideration, when the motors are developing their rated horse power, the identity $ax = \beta\ 100$ is simply a mathematical statement of my assumption that the speed (ax), at the instant after the initial period of acceleration is completed, is equal to the full load speed of the motors ($\beta\ 100$), and I have a perfect right to substitute one of these quantities for the other.

The values of β thus derived, substituted in curve sheets 6, 7 and 8 of Dr. Hutchinson's paper, give me the speed, distance traversed and energy expended per ton, tabulated in my tables A, B and C, and summarized in the curves of my Fig. 4, for the accelerations $a = 1$, $a = 2$, and $a = 3$. Stated as a practical problem, I have only assumed that it is possible to gear the same equipment for a higher or lower initial acceleration with the same full load current of the motors, and I have derived from the formulæ of the paper the characteristics of operation corresponding to the accelerations $a = 1$, $a = 2$, $a = 3$.

Dr. Hutchinson is guilty of another error when he says I have " used the wrong equation to calculate the input, the equation (23) is the correct one." If he had noted my words, he would have seen that I have nowhere used equation (18) to calculate the *input*, but have uniformly used it, as defined in his paper, to express the power *developed by the motors* at the car axle. It is, however, absolutely immaterial to me what equation I use to obtain the values of β corresponding to various values of a. Any equation in his paper expressing the relation between these two quantities would have served my purpose as well. Suppose we use equation (23).

$$P = .213\ (a+b)\ \beta\ x \qquad (23)$$

The coefficient differs from that in (18) by the factor .85, expressing the efficiency of the motors, but the relation of β to a is exactly the same as was derived from equation (18), and for the same equipment I can derive the same values of β corresponding to different values of a as I have already derived from equation (18).

I wish to criticize in this connection Dr. Hutchinson's use of P in (23) as expressing *input* to the motors while the same symbol is used in (18) to express a different quantity, the power *developed* by the motors.

I maintain that the above review of my discussion effectually disposes of Dr. Hutchinson's statements that I have incorrectly handled his formulas.

His only remaining criticism is in regard to my interpretation of the results summarized in the curves of my Fig. 4. While he admits that the curves show a maximum energy consumption with a minimum acceleration at the same schedule speed, he claims that "these values are not comparable as they are obtained under entirely different conditions." On the contrary, I maintain that the conditions are absolutely the same. We have assumed the same equipments, taking the same starting currents, the same length of run, and have arrived at curves showing the energy used for making the same schedule speed with different initial accelerations. He says my results only "show the difference in energy required for more or less use of the motor curve." I am perfectly aware that the increased economy is due to increased use of the motor curve. I cannot conceive of a variation in the initial acceleration which does not necessarily involve a corresponding variation in the use of the motor curve, the power of the equipment and the schedule speed being maintained constant. This, I have always considered, is the secret of the economy of high acceleration. If, however, Dr. Hutchinson has "elaborated a method that gives the effect of varying the initial acceleration on the energy and motor capacity" and by which he can maintain the same amount of use of the motor curve while he varies the initial acceleration, and still make the same schedule speed over the same length of run, he has failed to develop that phase of his investigation very clearly in his paper.

In closing, I wish to say that I do not wish to be understood as making any criticism on the general conclusion of his paper, in which he states: "The best initial acceleration to adopt is that acceleration giving the minimum motor capacity." Of course, it is understood that the words "for a given schedule speed" are tacitly assumed in this conclusion. With that correction, that is a statement which it did not require the array of figures Dr. Hutchinson has marshalled, to command the assent of every railroad engineer, whether practical or otherwise.

What I do criticize is his further conclusion that the lowest acceleration is the most economical, or, as he stated in his paper:

"The result is always that the energy used per mile is less for the lower accelerations." It was this conclusion that I challenged in my discussion, and I maintain that by applying the formulæ and curves of his own paper to a particular case, such as would be met with in ordinary operation, I have proved that at least this is false as a general conclusion and is not of universal applicability.

[COMMUNICATED AFTER ADJOURNMENT BY MR. W. C. GOTSHALL.]

Although I have already called attention to the action of Dr. Hutchinson in making a number of assumptions in order to arrive at erroneous conclusions and results, I cannot allow his last assertion, to the effect that I have not read his paper, to remain in the record unchallenged.

I read Dr. Hutchinson's paper a number of times, as did also my associate, Mr. Mailloux, who devoted many days in trying to adapt Dr. Hutchinson's results and conclusions to what we knew to be correct. We are just now in search of any and all data and information upon heavy and high speed electric traction, and have not been able to apply successfully the results, or the methods of Dr. Hutchinson, in our professional work, and we believe that his conclusions are in error. For instance, the run-sheets referred to in my discussion are the results obtained by taking into consideration all the known factors, and they clearly refute the conclusion of Dr. Hutchinson that the economy due to rapid acceleration is insignificant.

The first reading of his paper was followed by a feeling of perplexity, which has been augmented by Dr. Hutchinson's statements in his reply to the discussion. If, as stated in his reply, the particular results and conclusions of the author are based upon assumptions selected to suit his conclusions, which, apparently, are incapable of application in practice, the paper must stand as a purely academic production, because it falls of its own weight when analyzed by reference to the only other proper criterion, to wit: Practical application.

Again, I happen to have knowledge of the New York Subway rapid transit results thus far obtained, having carefully investigated, among other matters, their express service run-sheets and the bases of their derivation. It was on account of my being fortified with such knowledge, that I referred to it in my discussion, hoping for a relevant reply from Dr. Hutchinson. He passes over the subject with the statement that the service as proposed could not be made "under the assumptions" of his paper, in view of which I can only ask: If the formulas and results of the paper are inapplicable to conditions of practice, of what use are they?

The paper is remarkable for its lack of lucidity, as well as its vagueness. Practicing engineers have little time to devote to the derivation and verification of complex formulæ, and such work is generally only done to check the results of a new treatment of an important subject. Such work is rendered manifoldly arduous when a new treatment of a subject is symbolically confused. As an illustration of ambiguity and perplexity in notation, I would call attention to the double use of the Greek letter "delta." In equation (22) this letter is used in the correct classical and universally accepted manner, as a qualifying symbol denoting an increment. In equation (27), however, and in the reasoning which precedes it, the same symbol is used as a constant, denoting an area, and, at first blush, one would naturally read equation (27), to be A minus the increment of the quantity within the brackets. It is my impression (although I would not be too sure), that the author intends it to mean the *product* of the quantity enclosed in brackets by the coefficient or factor delta. In some cases, the sign of multiplication, or the sign of equality, could have been used to advantage. On page 142 one is not sure that the formula is intended to give the results in kilowatts, or that the kilowatts are to be multiplied by the other factors in the equation. In the various formulas given on page 130, the sign of multiplication is implied between the numerical factors and the written factors, such as "feet per second" or "miles per hour." Making the same assumption in the case of the statement given in the middle of page 130 would hardly be safe, however. It seems to me, that, in this case, the sign of equality should precede the term "kilowatts."

I understand discussions to be for the purpose of bringing out from the author of a paper explanations relating to any assumptions he may have made, or for clarifying any obscurities. Dr. Hutchinson's general remarks, in his reply, were an arraignment of the participants in the discussion, for venturing to indicate hypothetical assumptions made by him in arriving at erroneous conclusions. His arraignment was based upon the apparently equally unwarranted statement of his, that the participants had not read the paper. He either could not, or would not; at all events, he did not, add one iota of light to what, I hope, is a misunderstood effort.

In conclusion, I reiterate: That the results and conclusions are in error; that the paper is not *a general solution*, "*covering all cases which can arise in ordinary practice*," (Hutchinson's paper, first paragraph), and that its adaptability to any practical case is not apparent, and has not been subsequently shown by the author.

A paper read at the 161th Meeting of the American Institute of Electrical Engineers, at New York, Feb. 14th, 1902.

STATIC STRAINS IN HIGH TENSION CIRCUITS AND THE PROTECTION OF APPARATUS.

BY PERCY H. THOMAS.

It is the purpose of the present paper to discuss the so-called "static effects" in high tension circuits, especial attention being given to the disturbances produced by lightning, switching, grounding and the like. Some discussions of particular phases of the principles involved have been published from time to time, but so far as has come to the attention of the author, no comprehensive treatment of the subject of a non-mathematical character has yet appeared. On this account a general view of the question without mathematical complication will probably prove of interest to superintendents and station managers as well as to electrical engineers. Necessarily much of the matter in the paper will not be new, but it will be found that the old principles when applied to commercial circuits yield quite novel and important results.

It is scarcely necessary to state that static strains, though not perhaps particularly destructive of themselves, may indirectly cause the loss or temporary disabling of expensive and important apparatus; and more is involved than the loss of the apparatus. One of the principal aims, if not the chief aim of the superintendent of a modern electric transmission system, for the accomplishment of which he will make great sacrifices, is to keep his service continuous. Static disturbances in such systems, when not properly controlled, are a constant menace to the continuity of the service. The prominence of static effects is one of the chief distinguishing characteristics of high tension operation. The importance of " static " is not emphasized solely on theoretical grounds. Plants in actual operation have suffered both damage to apparatus and loss of prestige on account of insufficient static protection.

The paper will be divided into two parts.

I. Nature, Causes and Effects of Static Disturbances; and

II. The Protection of Apparatus and the "Static Interrupter."

PART I.—NATURE, CAUSES AND EFFECTS OF STATIC DISTURBANCES.

INTRODUCTORY.

The term "static" is certainly a misnomer, as the most prominent characteristic of the phenomena thus designated is the abrupt and violent nature of their discharges of electricity. However, this group of phenomena is so clearly defined and is so generally recognized by this name that in the absence of a better term of general acceptance its use will be continued. A new term, however, is very greatly to be desired, and as the phenomena described are essentially those of wave motion, the author recommends the word "*undic*" as a substitute for "static."

For the present discussion "static" (or "undic") will be taken to include those changes of potential and waves of current of an abrupt nature which result from the transfer of the electrostatic charges of a system from point to point. Such actions are not directly produced nor controlled by the generator. I say "not directly," for, of course, practically all electrical phenomena in a circuit, except those due to lightning, are produced at least indirectly by the generator.

Every electric circuit may be viewed in two ways. It may be regarded (as in dealing with the transmission of power) as a closed circuit containing resistance and inductance, and carrying a certain current produced by a certain e.m.f., or it may be regarded (as in dealing with static) as a large insulated "conductor" (as the term is used in treatises on static electricity) of peculiar form. That is, the circuit performs a double function. It transfers useful energy and at the same time acts as an electric condenser. The first aspect, being the one of greatest practical importance, is the one almost universally considered. However, even in this case, with long high tension lines, it has been found necessary to give some attention to the e.s. (electrostatic) capacity of the circuit taken as an insulated "conductor." The second aspect of the circuit is the one to be here considered, and though of less importance than the first, it still deserves careful consideration on account of the serious difficulties static may cause in commercial work. As a matter of fact, since the electric circuit when operating is at the same time both a closed circuit carrying current and a charged insulated " conductor," the actual resultant condition of the system is a combination of these two states.

There are some points of difference, however, between the commercial electric circuit and the insulated " conductors " commonly used in the laboratory demonstrations of static electricity. In the first place the commercial circuit is very much the larger and is extended over greater distances, so that a sensible time is required for an electric impulse to pass from one end to the other. Consequently, two points on the same conductor may be momentarily at very different potentials. In the second place the amount of energy stored in the e.s. capacity of the commercial circuit is very much larger than that in the " conductors " of laboratory experiments. It should be noted that these points of difference are both difference of degree, not of kind.

It will be well at the outset to summarize briefly the most characteristic of the laws of static. These are all well known and of very general applicability, viz.:

LAWS OF STATIC.

I. A static discharge (which is merely a very sudden rush of electricity) encountering a choke coil in its path, experiences momentarily great opposition, *i. e.*, the electricity is temporarily held back by the inductance of the coil, so that if the rush of electricity be of large volume and sufficiently sudden, a very great e.m.f. (neglecting losses of energy) will be exerted on the choke coil. This high e.m.f. is but momentary, however, as the choke coil after the first instant allows the electricity to pass at an accelerating rate which soon relieves the pressure. The high momentary pressure at the front of the choke coil causes a tendency for the charge to seek other paths. Such a phenomenon would be called " side flash " and is one of the considerations which led to the use of choke coils with lightning arresters. Lightning arrester choke coils are so placed that any static disturbance on the line must pass the choke coil to reach the apparatus which is being protected, and the arresters are placed on the line side of the choke coils, where the tendency to side flash is strongest.

As there is a tendency to side flash toward other objects, there must evidently also be a tendency to short-circuit the choke coil itself. Such short-circuits are by no means unusual when coils not designed to withstand them are exposed to static discharges,

II. All conducting bodies have e.s. capacity or in other words are to a greater or less degree condensers. Whenever a conductor is at a potential different from a neighboring conductor, a charge of electricity appears in its surface principally on the side toward the other body. The amount of this charge equals the product of the e.s. capacity and the potential between the bodies. At the same time an exactly equal charge appears on the second body. A conductor may have capacity to two or more adjacent conductors at the same time; in this case its resultant charge is the sum of the separate charges.

The fact that a certain quantity of electricity, great or small, is required to charge any conductor to any definite potential is very important in its bearing on long distance lines. Suppose, for instance, that a piece of apparatus at one end of a transmission line is to be raised to a certain potential by a sudden application of voltage at the other end. A sensible time will elapse before the necessary charge for the apparatus can reach the end of the long line. Consequently, the potential of the apparatus will not rise at the same instant as the applied e.m.f., but will remain unchanged until charge actually reaches it. In other words, the potential of a condenser cannot rise until the charge necessary to produce this rise has entered it.

The large current required to charge the line wires of an extensive high tension system is well known. All switches, transformers, instruments and other apparatus actually connected to the high tension circuit also require charge, though of course much less.

The line wires have e.s. capacity both to the earth and to one another. The several charges corresponding to those different capacities though superposed on the wire, act independently of one another and must be so studied. Similarly with apparatus connected to the lines, not only will there be e.s. capacity in the high tension parts to ground and low tension parts, but also between different parts of the high tension windings themselves.

III. When a current is flowing through a circuit containing inductance, energy is stored in its magnetic field. The amount of this energy equals one-half the product of the inductance and the square of the current. This energy was obtained from the circuit when the current was started, and when the e.m.f. producing the current is removed, must be discharged back into the circuit before the current can stop. If the circuit be suddenly opened, a very high potential will be developed to keep the current flowing until this energy is fully discharged. Such is the case of the well-known rise of potential which results from suddenly opening the field circuit of a large generator. The direction of this " extra " e.m.f. is such as to continue the current flow.

Energy in a magnetic field is just as truly stored energy as that in the moving bullet, the stretched spring, or the raised weight. It may be adapted to useful purposes. For example, the energy stored in the magnetism in the core of an induction coil by the primary current, is discharged into the secondary to produce the high tension spark.

An idea of the amount of this energy in actual cases may be obtained from the following: One ampere flowing through a coil with an inductance of 1 henry (equivalent to 377 ohms at 60 cycles) stores $\frac{1}{2}$ volt-ampere-sec = $\frac{1}{2}$ watt-second, = $\frac{1}{2}$ joule = 0.367 foot-pounds.

The very sudden rushes of static electricity are no exception to this law; they produce magnetism and store energy which must be discharged into the circuit again before the currents can cease. This principle will be found to lead to important results.

Also, when a condenser is charged, energy is stored. This energy will be restored to the circuit again when the condenser is discharged. The amount of this energy is one-half the product of its e.s. capacity and the square of the voltage.

A condenser of one microfarad capacity charged to 1,000 volts potential stores $\frac{1}{2}$ a watt-sec. = $\frac{1}{2}$ joule, = 1.367 foot-pounds.[1]

1. The transmission lines of a system like the Bay Counties Power Co. of Cal., with lines 150 miles long, have a capacity of about 3 microfarads. Operating at 40,000 volts, this will have $1/2 \times (3 \times 10^{-6})\ (40{,}000 \times \sqrt{2})^2 =$ 4,800 watt-secs = 4,800 joules, = 3,500 foot-pounds of energy stored in its e.s. capacity when fully charged. The charging current is 45 amperes at 40,000 volts, 60 cycles. Therefore, the rate of supply of energy to the line from the generator and absorption from the line by the generator is $45 \times 40{,}000 \times 2 \times \frac{1}{\tau} =$ 1,150,000 watts, = 1,150,000 joules per sec., = 843,000 foot-pounds per sec. The generator supplies current continuously to the line for $\frac{1}{4}$ cycle and then receives it back again for the next $\frac{1}{4}$ cycle. Therefore, the energy delivered or received in a half alternation is the energy stored in the capacity of the line, $= \frac{45 \times 40{,}000 \times 2}{\tau \times 60 \times 4} =$ 4,800 watt-secs. = 4,800 joules = 3,500 foot-pounds, as before.

The energy of an electric current may thus be stored in two ways: either in a magnetic field produced by a current, or by the storing of the electricity itself. In its former state the energy may be regarded as kinetic and in the latter as potential.

Electric Circuit as an Insulated Conductor.

It has been stated that an electric circuit may be considered as an insulated conductor of a peculiar form. It is rather an aggregation of conductors of various forms. In general a high tension circuit consists of the following parts:

(*a*) High tension windings of transformers, raising and lowering.

(*b*) Transmission wires.

(*c*) High tension switches, instruments, lightning arresters, station wiring and similar auxiliary apparatus.

(*a*) The high tension transformer windings are in the form of coils, and are therefore from the static point of view, choke coils. On account of the very large number of turns their choking power is very great (choking power in general, being proportional to the square of the numbers of turns). The high tension windings have e.s. capacity also, as they lie close to the low tension windings and to the core, that is, the high tension winding will have static charges on the surface opposite the low tension winding and opposite the core. There is as well, capacity between turns and between coils of the high tension windings. The e.s. capacity of these transformer coils is of a rather complicated nature, for it is distributed along at different points on the winding, and is not concentrated at one point as in an ordinary condenser. Therefore, the charge for the different portions of the windings must pass through different lengths of wire and different amounts of inductance and resistance. The same is true of both raising and lowering transformers.

(*b*) The transmission wires have e.s. capacity with one another and with the earth, so there are two or more charges superposed on each wire—each of which may act independently of the others. This capacity, though comparatively small for short lengths of wire is, as a whole, large, on account of the great length of the lines. These wires have inductance also, like the capacity; small for short lengths, but quite considerable when the line is taken as a whole

On the line wires, as in the high tension transformer windings, the e.s. capacity and inductance are distributed, so that when voltage is applied to the line, different points receive charging current at different instants of time, since the charge for various points must flow through different lengths of line. In fact, the transmission wires may be considered as a succession of choke coils and condensers in series, each very small, but very great in number, as shown in Fig. 1.

In addition to the e.s. capacity of the line wires, there is a certain amount of capacity on each insulator. The amount is very small, and may be considered a part of the line capacity.

(*c*) Switches, instruments, lightning arresters, station wiring, and similar auxiliary apparatus have a certain amount of e.s. capacity to surrounding objects, but not usually as much as the high tension windings of transformers. This part of the system has also comparatively little inductance and needs no further discussion here.

In addition to e.s. capacity and inductance, all parts of the high tension system have more or less ohmic resistance. The

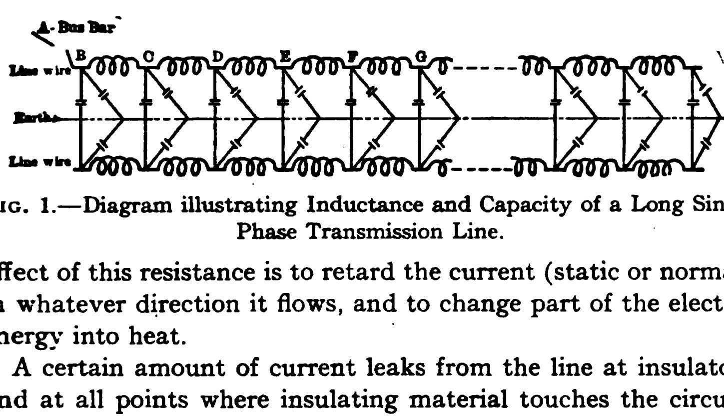


FIG. 1.—Diagram illustrating Inductance and Capacity of a Long Single Phase Transmission Line.

effect of this resistance is to retard the current (static or normal) in whatever direction it flows, and to change part of the electric energy into heat.

A certain amount of current leaks from the line at insulators and at all points where insulating material touches the circuit, since no insulation is perfect. Even the air conducts away some charge when the voltage is extremely high. Taken altogether, the result of these leakages is small under normal conditions, and may be neglected in this discussion.

Every point of a high tension circuit at any instant has a perfectly definite potential, which is in general different from the potential of other parts of the circuit and of adjacent objects. Consequently each point has at each instant a definite static charge, often different from that of other points. As (with alternating currents) the potential of each point is varying from instant to instant, these charges are continually changing and the changing charges cause a current in the circuit properly called charging current. Neither this charging current nor the static charges have any connection with the useful current except as the latter may influence the static potential of some point of the circuit. The total current in the circuit at any instant is the sum of the work current and charging current, if they are in the same direction, or their difference if they are in opposite directions.

When the potentials of all points of a circuit are determined directly by the electromotive force of the generator, *i.e.*, during normal operation, all changes of potential are slow (compared with static changes of voltage) and allow sufficient time for the necessary changes in the static charges at various points to be accomplished without serious opposition from the inductance of the circuit. Such changes of potential and charges as these, however, are not the subject of this paper. Its principal object is the discussion of changes of potential of a more abrupt nature which are not directly produced by the e.m.f. of the generator; the latter may cause violent and sudden alternations of the static charges and dangerous local potential strains. However, before taking up the more complicated case of the abrupt changes, it will be best to consider a little more fully, the distribution of potential and charge in some of the simpler cases of normal running, viz.:

Static Charges on a Symmetrical Single-phase Transmission Line Open-Circuited at the End, and Charged by a Direct Current Generator.—In this case both lines have the same e.s. capacity to the earth. There is also capacity between the line wires. On the positive line is a positive charge composed of two parts, one due to its capacity to earth and the other to its capacity to the other wire; similarly on the negative wire is an equal negative charge composed of two parts. These charges remain constant as long as the e.m.f. of the generator is constant.

If, however, the generator be an alternator, the charges change from positive to negative with the voltage, remaining equal on the two wires at all times. This interchange of charges requires a flow of current from line to line through the generator.

When the same line is loaded at the farther end no material change is produced in the line charges. Since different parts of the high tension winding of the motor or transformer or other apparatus constituting the load, are at potentials varying all the way from one-half line voltage positive to one-half line voltage negative, the charges on these points will vary in a similar manner. These charges are supplied from the generator through the line. The charges for the inner parts of the winding of the load apparatus must flow through the outer parts of the winding as well as through the line.

Same Line with One Leg Grounded.—Since direct current is practically never used in high tension work it will be omitted from further discussion here. The case of a grounded line is of importance not as a practical operating condition, but on account of the harmful results which may follow accidental grounds. The potential of one line wire becomes the same as that of the earth, while that of the other is full line voltage, double its value with circuit ungrounded. The potential between the wires being maintained by the generator, remains unchanged. Of the two component parts constituting the charge on the ungrounded wire, the part due to the e.s. capacity between the wires in undisturbed by the grounding, since the voltage between wires is unchanged, but the part due to the capacity to earth is doubled since the potential of the line above the earth is doubled. On the grounded line the part of the charge due to the e.s. capacity between wires is unchanged—the part of charge due to capacity to earth becomes zero, since the potential to earth is zero. The charge which appears on the earth opposite the ungrounded wire and which is equal in amount to the part of that line's charge that is due to capacity with the earth, being produced by the generator, must flow to earth at the point where the circuit is grounded. On a large system the e.s. capacity of the lines would be sufficient to make this current quite large. In such a case the current may burn off the line wire at the grounded point if the contact with the earth is imperfect. This fact has a very direct bearing on the question as to whether it is possible to operate a large high tension system with one wire accidentally grounded.

System with Neutral Point Grounded.—In a symmetrically arranged ungrounded system either single phase or polyphase, a neutral point may be defined as any point which is at the earth's potential. There may be more than one neutral point in a circuit as shown in Fig. 2, where *a b c d* are neutral points.

Since the neutral point is at the earth's potential, grounding this point makes no difference in the potential or charge of any point of the circuit, and no current flows over the grounding wire. If the circuit becomes unbalanced, for example, by a high resistance ground on one wire—there is a tendency for the neutral point to take a potential different from that of the earth, and a current will then flow over the grounding wire, which will be sufficient to keep the neutral point at earth's potential. If there be a dead ground on one wire the earth connection at the neutral point completes a short-circuit. If the neutral point is not grounded when the system becomes unbalanced, one or more lines will take a potential higher above the earth than in the balanced condition, and the other line or lines a potential lower than before. Therefore, comparing the two methods of operation—with the neutral grounded, if a " dead " ground is made on any line wire, a short-circuit is produced through the ground connection at the neutral point; with the neutral undergrounded a ground on a line wire means approximately twice the previous potential between line and ground on one or more wires, though no short-circuit is produced. The advantage of a grounded neutral is the preventing of increased potential over the earth in case of

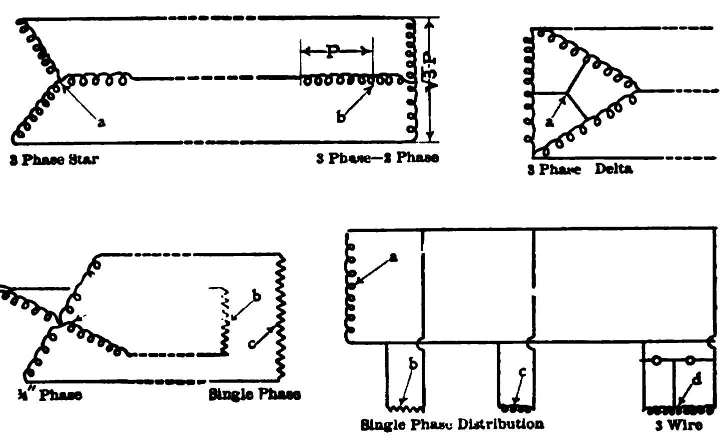


FIG. 2.—Neutral Points.

an accidental ground, its disadvantage is the fact that one such accidental ground, instead of two, causes a short-circuit.

We may now consider some of the abrupt changes of potential not directly produced by the generator.

1. *Connecting " Dead " Transformer to Live Line.*—Fig. 3 represents the portion of a high tension transformer coil connected to the line terminal. The circles indicate wires. The coil may have one or more turns per layer. The numbers on the circles indicate the order in which the current passes through the turns of the winding. The low tension winding lies adjacent to the high tension and the small condensers *a b c d*, etc., shown dotted, indicate the e.s. capacity of the corresponding wires to the adjacent low tension coils.

Before either terminal of the transformer is connected to the line, all parts of the high tension winding are at earth's potential. As the first line switch is being closed at s, there is no change in the potential of the transformer winding until a spark passes between the switch jaws. Then instantly the potential of the transformer terminal is raised to the potential of this line wire. The rest of the high tension transformer winding also takes the potential of this line wire as soon as (but not sooner than) the necessary charge can reach $b - c - d - e$, etc. Now, the charges for $b - c - d - e$, etc., must flow through a considerable amount of inductance, which will require a length of time which is very short but still sensible. It is clear that during this short but definite period, after the terminal has reached its full potential and before there has been sufficient time for charge to reach the

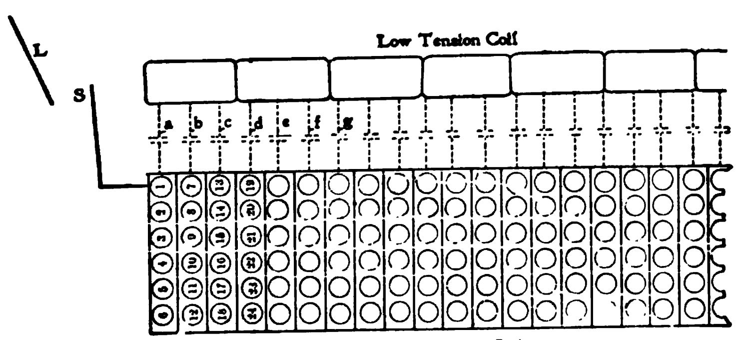


Fig. 3.—Diagram Illustrating e.s. Capacity of a High Tension Transformer Coil also Charging from a Live Line.

inner layers, for example, f and g, etc., a difference of potential exists between the outer and inner layers of the winding, which is equal to the full e.m.f. of the line wire above the earth. If the insulation of the winding is too weak, or the line potential is sufficiently high, this momentary difference of potential will cause a spark to pass over the surface of the coil or through its insulation. This spark contains a very small amount of electricity, for as soon as the wires, f, g, etc., are charged up to line potential, the voltage between the inner and outer layers vanishes. The only result is the almost harmless passage of a nearly invisible spark.

Very soon after the closing of the first line switch the whole transformer winding will have assumed the potential of the first line wire, that is, just before the closing of the second line switch the second transformer terminal is at the potential of the first line. As the second switch is closed, a spark passes, and the potential of the second terminal of the transformer which has up to the instant been at the potential of the first line, is suddenly changed to that of the second line—a very abrupt change. Then, as before, during the period required for the necessary charge to penetrate to the inner turns, a very high potential difference is impressed on the outer portion of the coil. The momentary strain on the insulation of the coil is greater when the second switch is closed than the first, for the first transformer terminal experienced an abrupt change only from earth's potential to line potential, while the second was changed from the potential of one line to that of the other line, which is nearly double the potential from the ground.

There is another very important difference between the effects of closing the first and second switches in connecting a "dead" transformer to a live line. In the case of closing the first, as already stated, if the momentary strains break down the insulation, only sufficient current flows through this break to charge up the inner layers of the transformer coil. This is a very small quantity and can do comparatively little injury to the coil, especially if it be oil-insulated. In the second case the amount of current passing in the static spark is not very materially greater than in the first case. But when the insulation between turns is momentarily broken down by this small spark, there flows through the break a certain amount of current due to the e.m.f. impressed by the generator on each turn of the coil. Although the static spark of itself would be but momentary, yet the current supported by this impressed or "normal" e.m.f. of the circuit may be able to hold the arc and continue indefinitely, destroying the whole coil if not interrupted. I say *may* be able to hold an arc, for such an arc may or may not be held, according to the circumstances of the case. If the static spark passes when the normal e.m.f. is nearly zero, or if the transformer be not able to supply much current in short-circuited turns, etc., then the chance that a permanent arc will be established is small. Sparks or flashes have actually been observed in the winding of high tension transformers at the time of lightning discharges, showing actual temporary holding of an arc.

The factors which determine the minimum number of layers upon which excessive momentary potential will be impressed are, chiefly, the inductance and e.s. capacity of the transformer coils and the abruptness of the change of potential of the terminal on the closing of the switch. The former determines the rate at which the charge can penetrate the coil, and the latter determines the time during which charging current may be passing into the coil before the full potential is reached on the terminal. The more abrupt the spark and the greater the capacity and inductance of the coils, the fewer the number of layers which will become charged before full terminal potential is reached, and the more severe will be the strain on insulation.

When switching is done on a high tension generator or a motor or any apparatus containing coils, a strain is brought in the windings near the terminals in exactly the same way as with transformer coils. There is also, usually, this same tendency for normal voltage to cause an arc to follow any momentary break in the insulation.

It is evident that the danger from this sort of switching is greater and greater for higher and higher voltages—it is of little importance on low voltages. Actually, injury of a serious nature to apparatus from this source is very much less than would be at first expected for several reasons:

(*a*) Insulating materials will stand much higher voltages of a static nature than of a continuous nature, such as those derived from generators.

(*b*) The passing of a static spark alone is usually by no means a serious matter and many circumstances may prevent a destructive arc from following the spark.

(*c*) It is only occasionally that the combination of circumstances arises which gives the severest conditions.

It has been assumed thus far that the potential of the line wires is unaffected by the switching operations. If, however, the connecting of the transformer to the line momentarily lowers the line potential at the switch, as will often occur, the abruptness of the static strain, and therefore its severity will be reduced.

This discussion which has been applied to switching on a transformer, is applicable when any coil is subjected to an abrupt change of potential in any part. For example, when a dead transmission line is connected to a live transformer the potential of the transformer terminals will usually be suddenly lowered very considerably for the moment, on account of the great excess of e.s. capacity in the line over the transformer coil. In this case the potential of the line which must be charged directly by the generator (and not from charge previously necessary amount of electricity already stored in condensers connected directly to the circuit. In commercial plants the place of such condensers is supplied by other live lines connected to the bus bars.

The strain of double potential produced by charging a line has an interesting analogy. If a piece of metal be tested for tensile strength by suddenly applying a weight on the end, a double strain will be momentarily given the metal due to the slight motion of the weight allowed by the stretching of the test sample. In this case the inertia of the weight corresponds to the inductance through which the line is charged.

The discussion so far assumes that there are no losses of energy in resistance or in currents set up in adjacent bodies. Such losses, which always exist to some extent, tend to reduce both the amplitude and the number of oscillations.

CHARGING A LONG TRANSMISSION LINE.

In the case of a long transmission line, however, the line cannot properly be considered to be a simple condenser, for this is equivalent to the assumption that the line is so short that its inductance is practically zero, and in actual long lines such is not the case. To present such a line, however, we may take a succession of choke coils and condensers connected in series, as in Fig. 1. Consider a single line wire open circuited at the receiving end.

The " dead " line is to be charged at the end, *B*, from the high tension bus-bar, *A*. Assume that, as the switch at *A* is closed, the point *B* is instantaneously raised to full potential. If now the line extended no further than the condenser *C*, we should have the case of a short line which has just been discussed; that is, the line will rise to double potential and oscillate until it finally settles down at normal potential. But since the line shown in Fig. 1 does not end at *C*, as soon as the potential of condenser *C* begins to rise, current begins to flow to condenser *D*, and as *C* rises higher and higher, more and more current will flow to *D*. The potential of *D* then begins to rise, which starts current to *E*, etc. As *D* rises slowly at first, *C* reaches bus-bar potential before *D*, and similarly *D* before *E*, etc. As soon as *C* reaches this potential it remains constant. At the same instant that *C* reaches bus-bar potential the current value in the coil between *B* and *C* reaches a maximum and becomes constant. Similarly with the currents in the other coils. This final current, which appears in more and more coils as the line charges up, supplies the charge that is being added constantly at those points where the potential is changing, to continue the process of charging, though the potential of C remains constant, that of D continues to rise until it reaches the same value as C, when it too becomes constant, though the potential of E continues to rise, and so on along the line. Similarly with E and F, but each successive condenser reaches its maximum a little behind those nearer the point A, so that the net result is a wave of e.m.f. starting at the point B and passing along the line.

The general distribution of the potential of the line showing the wave form at short intervals of time after connecting on the line is shown in Fig. 4.

This wave passes along leaving the lines fully charged. If the line be infinitely long it will experience no further disturbance. and if there are no resistance or other losses the wave will pass along to an indefinite distance, keeping its form and raising in turn all parts of the line to the full bus-bar potential. If there be considerable losses of energy as the wave proceeds (as there usually are in any actual circuit) this wave will lose its shape somewhat, and will get feebler and feebler, until, if the line be long enough, it ceases to be perceptible. This dying away of intensity may be slow enough in commercial lines, so that a large part of the original intensity of the wave will remain when the end of the line is reached. Now, the end of the line is open circuited, and the wave of electricity can go no further and is reflected back. At the reflecting point the maximum potential reached is twice that of the wave.

On being reflected, the wave immediately starts back along the line, leaving it charged to double potential (assuming no losses), and finally reaches the starting point, A, where its energy is absorbed by the bus-bar. But the line cannot stay at double potential, and a second wave is sent along the line, bringing it back to normal potential again. This second wave will be reflected at the open end, and will return again, but this time dropping the potential of the line to zero until, as the wave reaches A again, the line is practically in its initial condition. This wave, in turn, is absorbed by the bus-bars, and the whole series of operations gone over again and again. If, however, there are resistance and other losses, the wave is growing thinner and thinner all the time, and finally dies away, having only partly charged the line. As the wave dies down by the resistance losses, an infinite number of small supplementary waves are sent out, which complete the charging of the line. If there are no losses, however, no supplementary waves will be formed.

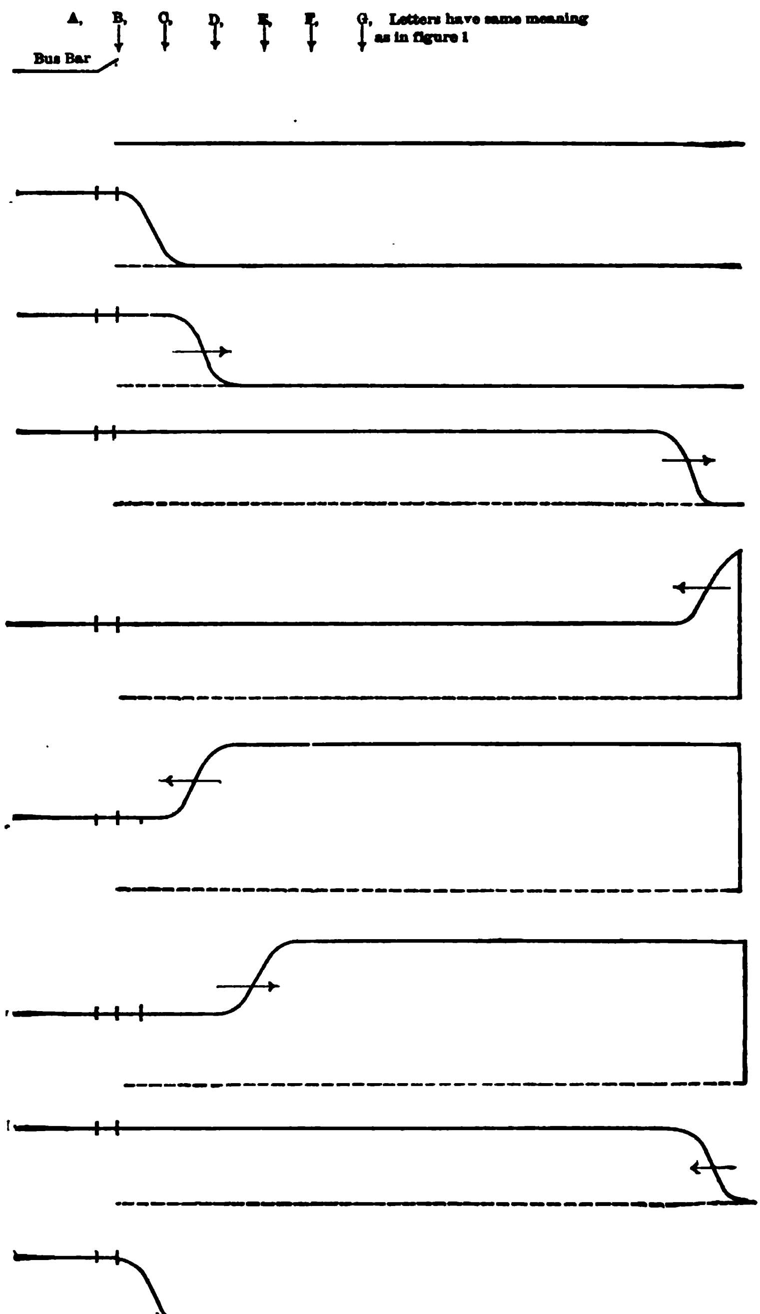


Fig. 4.—Charging Wave in a Long Transmission Line.

It will thus be seen that the charging of a long line is much the same as a short line; in both cases the line oscillates between zero and double voltage until the losses cause it to settle down at normal potential. These wave changes are indicated in Fig. 4.

Actual tests on commercial transmission lines suddenly charged have shown a rise of potential much greater than normal at the end farthest from the switching.

Suppose a stretched flexible cord fastened at one end and held in the hand at the other. A quick motion of the hand sideways will send a loop or wave along the cord, which will pass to the end, will be reflected back and will finally reach the hand again. This wave is analagous to a static wave in the transmission line.

Charging a Branch Line.

Consider a line consisting of two parts—the more remote having a much smaller capacity and larger inductance than the nearer. When a wave starting from the beginning reaches the junction it will be partially reflected, since the whole charge of the large line cannot be crowded into the capacity of the small line, especially in view of the increased inductance of the new portion; that is, there will be a rise of potential at this point and a wave smaller than the outgoing wave will start back. As the original wave will not be wholly reflected, the potential at the juncture of the two circuits will not be double the charging voltage.

But a wave will also be sent forward into the second part of the line, which will have a crest as high as the maximum of the potential at the reflecting point. Therefore, at the end of the second line, where another reflection occurs, the crest of the last wave will be doubled. The resultant potential at this point will thus be very high, but not over four times the original voltage of the bus bar. It may be much less. This means that a branch line at the end of a main system (especially if the latter consist of two circuits in multiple) will receive a very severe shock at the farther end when a wave enters it from the main line. This is a case that may readily occur in actual plants and should be carefully considered. If there be a third line on the end of the second, leaving a still less capacity and still greater inductance, a wave will be formed in this line whose crest has the value of the maximum rise of the reflecting point at the end of the second section of line, and which will double its potential at the farther end as before. This last rise of potential has as its maximum theoretical limit eight times the original charging voltage, but would actually always be much less. This case is very unlikely to occur in actual circuits. The total energy in the waves in the second and third sections of lines is much less than in the original wave, but is at a higher potential.

To return to the consideration of the uniform circuit. It has been shown that when one end of a long line is suddenly raised to a certain potential and maintained there, a wave of charge passes along the line, leaving it charged, and that when this wave reaches the open end of the line it is reflected and produces all along the line a potential double that of the bus bar. If, however, a sine e.m.f. be momentarily applied to the line so that the end of the line is not maintained steadily at the full potential as before, but is immediately lowered, a wave will be found in the line as before, with the same maximum voltage but a different form. (See Fig. 5.) This wave leaves the line uncharged. The rise of potential at the reflecting point, however, is the same as long as the crest of the wave is the same, but in this case only the reflecting point receives double potential (assuming that only a single wave is sent into the line).

If a wave be started at one end in a very long, narrow trough of water, it will proceed the length of the trough and on reaching the end will be reflected and will rise up to double height at the reflecting point. This wave in the water is again analogous to the wave of charge passing along the line, leaving it unchanged and causing a double strain at the reflecting point.

In all cases of static effects the change in e.m.f. of the bus bars due to the generator is so slow that the generator e.m.f. may usually be considered constant while the static phenomena are taking place.

The length of the wave in the line is determined by two factors —the speed at which the charge passes along and the time required to bring the potential of the first point of the line to its full value; it is the extreme distance to which charge has penetrated when the charging potential becomes stationary.

If the line is shorter than the length of the wave no complete wave will be formed, but reflection will produce the same rise of double potential at the end. The speed at which the wave will pass along the line is inversely proportional to the square root of the product of the capacity and the inductance per unit length (unit length = 1 earth quadrant = 6,200 miles)—that is, to the time constant. But on air lines the waves always travel at approximately the speed of light, so that there is an inherent relation between the inductance and capacity of an air line which at first thought is very surprising. This relation is expressed in general by the equation $v = 1/\sqrt{LC}$, or $L = 1/v^2 C$, where v is the velocity of the wave in air.

Evidently the more sudden the disturbance the more likely is the formation of a complete wave. In the extreme case when the length of wave is very much longer than the line (as in the case when the voltage is applied to the line very slowly) there is practically no wave formed and we have the plain charging of a condenser. This is also the case considered in discussing the charging of a short transmission line.

If the source of e.m.f. from which the line is charged cannot maintain rigidly its potential during charging, the line will be charged up by steps as already explained. The result is that a weaker wave is obtained, followed by a second wave as the bus bar recovers its potential—which completes the charging of the line.

CHARGING AN UNDERGROUND CABLE.

What has just been said of charging a line applies equally well to an underground cable, only the cable has a much larger e.s. capacity and a smaller inductance than the transmission line. If a wave be formed in charging the cable, this wave will be reflected at the end, causing double potential all along the cable as it returns to the starting point. If, however, the cable be so short that no wave be formed, the cable will be charged like a short line, that is, as though it were a condenser. As before, if a momentary impulse up and down be given the cable instead of a steady charging voltage, a wave of the form shown in Fig. 5 will be produced, which causes double potential at the end of the cable, and there only when but one impulse is sent into the cable.

If a steady alternating e.m.f. is applied to a transmission line, waves will be sent along having crests of positive and negative values alternately and will be reflected at the end of the line one after another and return toward the starting point. When a returning positive crest meets an advancing positive crest, double potential will result at the point of meeting; similarly with two negative crests. When a positive and a negative crest meet, zero potential will result at the point of meeting. The result is the formation of nodes and loops in the line or cable, that is, points of zero and of double potential as shown in Fig. 6, where advancing waves are shown full, reflected waves dotted, resultant nodes and loops in dot and dash.

The waves sent into the line by the alternating e.m.f. are in continuous motion back and forward, but the nodes and loops are fixed in position though the loops vary in strength, alternating between positive and negative. This phenomenon is similar to the formation of nodes and loops in an organ pipe. There is always a loop or point of high potential at the reflecting point. The distance between two positive loops at any instant is the wave-length of the moving waves.

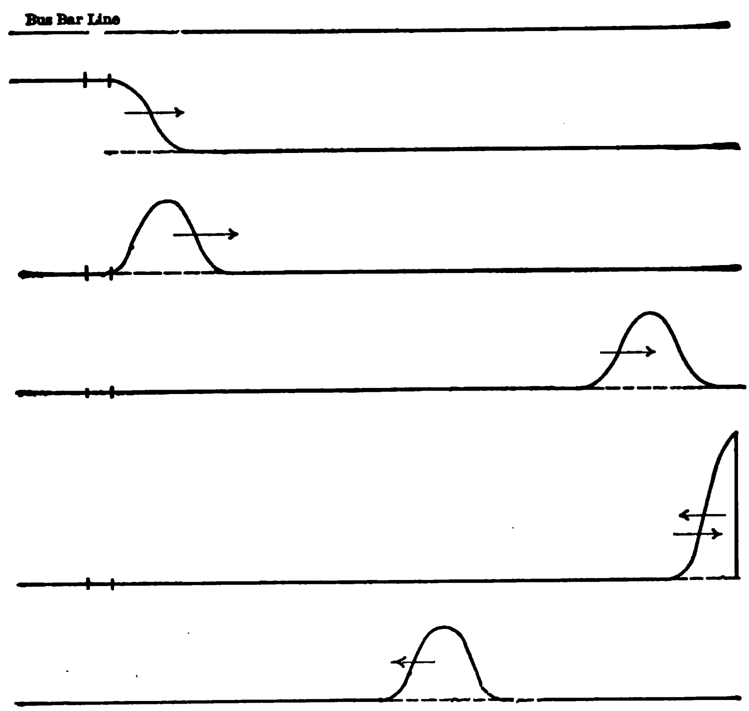


FIG. 5.—Charging Wave in Long Transmission Line.

To this point the lines and cables have been considered as open circuited at the farther end. Comparatively little difference will result in static effects, however, if they be closed through transformers at various points for the inductance of the transformer winding is so great that the comparatively large quantities of the charge on the line would not be materially lessened by the e.s. capacity of the transformers. In fact the transformer is subjected to a very severe strain without its being able to relieve the line. This strain is similar to that produced by connecting a "dead" transformer to a live line, since the rise of potential of the transformer terminal, due to reflecting the wave, may be very abrupt.

Opening a High Tension Circuit.

When opening a load current in a high tension line or cable no rise of potential will result unless the current be suddenly interrupted. With such an interruption, of course (as all commercial circuits contain considerable inductance), a rise of potential will result, its severity depending upon how suddenly the current is interrupted, how much magnetic energy is stored in the circuit, and how much e.s. capacity exists in the neighborhood of the break. This matter was treated by Mr. Steinmetz in his paper before the Institute last August. He there states that an excessive rise of potential may result from the interruption of

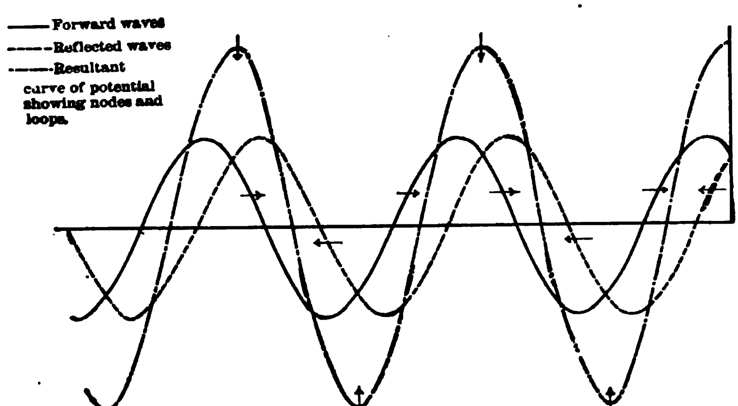


Fig. 6.—Nodes and Lopos in a Long Line or Cable.

short circuits. As a matter of actual experience, it is the opinion of the author that little rise of potential actually occurs from the opening of load or short circuit currents in commercial systems, as the resulting arc cannot drop out suddenly on account ofthe great amount of heat generated. There are often, however, other causes of static strains which may result from short circuits that occur at practically the same instant of time, and in some cases the results of one cause may be assigned to the other.

However, by opening an unloaded line or cable, it is entirely possible to obtain a rise of potential as follows: On opening a switch to cut out an unloaded line, the arc of the charging current tends to drop out when the current strength is zero, that is (since the unloaded line takes a leading current) when the voltage is a maximum; for as the line will momentarily hold its charge there is at this time little difference of potential between the line and bus bars, even after the switch is opened. The line is thus left charged when the switch is opened, while the potential of the bus bars is changing with the generator e.m.f. When the voltage of the generator has passed through one alternation there will be a potential between the line and bus bars, which may be sufficient to cause the arc to establish itself again and recharge the line. The arc will again drop out when the current becomes zero, and this action may be repeated several times before the line is finally clear. The sharp crackling sound often accompanying the switching out of a high tension line or cable suggests this phenomenon. This recharging of the line will cause the formation of a wave and the consequent rise of potential as in the case of charging a line. Thus, pulling off an unloaded line may have the same effect as charging it so far as the static rise of potential is concerned.

In the case where one terminal of the single-phase generator is grounded and charging current to a line is opened at the other, a static wave may be produced in the line of double the intensity caused by charging the line "dead," that is, a wave of double line voltage, giving a maximum rise of potential of four times.

Other Causes of Static Strains.

In the previous discussion the author has endeavored to show that dangerous static effects result directly from very abrupt changes of potential. They may appear in parts of the circuit very remote from the exciting cause. These static strains are phenomena, such as would be expected to result from well known laws governing static electricity. In addition to the causes of abrupt changes of potential already discussed, a few more will be briefly described.

(*a*) *Short Circuits.*—A short circuit between the two line wires, when of a sudden nature, causes an abrupt reduction to zero of the potential of one or both lines at the point of short circuit. This is the reverse of the case of charging a line. A wave is sent along the line, causing a dropping of the potential, which of course has no tendency to *ground* apparatus. Nevertheless, this wave causes just as severe a strain on the insulation between turns of the transformer coils next to line as a charging wave, for the potential of the transformer terminals is abruptly reduced. Since the inner layers cannot get rid of their charge immediately, there is a momentary potential across the coils between a high potential point in the inner layers and a low potential point at the terminal.

(*b*) *Grounds* —Grounds are also a cause of abrupt change of potential and short circuits. The same strain on coils is produced as before, strongest on the side of the circuit where the ground occurs; also the ungrounded lines are raised to full potential above the earth. It is true that the rise of potential of the ungrounded lines is not necessarily as abrupt, since it is produced partly by the generator.

It must be remembered that the static waves produced in lines by grounds and short circuits may have their intensity doubled at a reflecting point, so that the short circuit strain on coils is doubly severe at such points. However, the strains to ground are not great in these cases, except on the ungrounded wires.

It must be remembered that when a wave is caused by grounding or charging a line that the abrupt change of potential may sometimes be only the voltage existing between line and ground in that system and not the full line voltage.

In much of the previous discussion, transmission lines have been assumed to be single-phase. The conclusions arrived at are nearly all applicable to polyphase lines as well, with occasional changes which will be evident on inspection.

(*c*). *Lightning.*—Lightning is the best known cause of static disturbances. Unlike grounds, short circuits and switching, lightning usually does not act directly on the circuit, but indirectly by induction. Its effects, however, are of the same nature as those already discussed.

In general, lightning may affect a transmission line in two ways; by induction and direct by stroke.

(1) A lightning discharge in the neighborhood of an electric circuit but not actually reaching the circuit acts upon it indirectly by a combination of static and dynamic induction. The actual intensity of the effect in the circuit depends on the energy of the lightning discharge, on the distance to the circuit, its form and its position relative to the discharge path of the lightning and upon other conditions.

Lightning discharges are usually of an oscillating nature, that is, the charge on the cloud oscillates backward and forward between cloud and earth several times, pausing at each end of its path in each oscillation. This oscillating charge acts inductively on any electric circuit which is in the neighborhood, first (static induction), when pausing at either end of its path (by attracting a charge of the opposite sign to the nearest point of the circuit), and second (electromagnetic induction), since the actual discharge is a current and sets up an opposing e.m.f. in any parallel conductor. As the lightning charge appears first at one end and then the other of its discharge path, it draws the charge on the line back and forth, and the e.m.f. in the line induced by the current in the discharge is in such a direction as to accelerate the motion of the attracted charge. Therefore, the effect of the lightning discharge is to cause a static wave or a series of static waves in the line. These waves are similar in general character to those produced by switching, etc., except that there is no limit to their maximum possible strength. They may produce either grounds on windings or short circuits in coils, as circumstances may determine. The static strains produced in a circuit by lightning have no direct relation to the generator voltage, but are determined by the form and location of the line, the protective devices and the nature of the lightning discharge.

(2) A lightning discharge may and occasionally does strike a line directly. In this case it is commonly supposed that nothing can save the apparatus from injury. This may or may not be the fact, according to circumstances. If the discharge strikes the line at some distance from the apparatus, there is a very good chance that no harm may be done, for the choking effect of the line is enormous for the extremely abrupt discharge of a direct stroke. That is, the discharge cannot pass down a long line quickly, and instead will pile up voltage at the point where the line is struck and finally make some direct path to earth, usually by jumping to a pole. This relieves the line and no severe shock is sent to the station. The escaping discharge may or may not destroy the pole, according to the nature of the pole and the intensity of the discharge. But although the chief discharge passes to earth directly there will be a wave sent along the line, which may or may not do damage according to circumstances; thus, in this case the arresters are not required to discharge the direct stroke.

On the other hand, if the stroke is near the apparatus it is probable that protection will not be obtained from any lightning arrester. Even though the arrester were, for the moment, a direct connection between line and ground, there would be sufficient resistance and inductance in the ground connection and the discharge path in the earth itself, to prevent an absolutely free discharge and the result would be that the lightning would find other paths to ground. The case of a direct stroke by lightning near a station very rarely occurs.

(*d*) *Paralleling out of Phase.*—One more case of static may be mentioned. When two lines are thrown in parallel out of step there is an abrupt change of potential produced when the second leg of the paralleling switch is closed. This voltage change may run up to double line voltage if the generators are directly opposite in phase. The same effects may be produced when two generators are running in parallel by opening all the poles of the paralleling-switch except one, for the machines soon get out of step, and a discharge may pass between circuits—either over arresters or elsewhere. In this case a synchronous motor or rotary converter will act as a generator for a time long enough to cause any possible damage to be accomplished.

The most frequent causes of dangerous static disturbances in high tension circuits have been discussed. It is evident, however, that anything which causes an abrupt change of static potential of considerable severity may cause a dangerous strain on apparatus.

Resonance.—Resonance does not, strictly speaking, come under the head of "static," but to show its relation to the actions already discussed, some attention will be given it. As already frequently stated. any condenser discharging through inductance (the resistance being small) has an oscillating discharge as a pendulum has an oscillating motion. If now an alternating e.m.f. be applied in the discharge circuit of the condenser in such a way that the e.m.f. alternates just as often as the condenser discharges and is always in the same direction as this discharge, the intensity of the oscillations will get greater and greater, just as the vibrations of the pendulum will get greater and greater if an alternating force is applied to it in such a way as always to increase its swing. There is no limit theoretically to the voltage that may be reached after a sufficient number of oscillations, if there are no losses. However, in any actual trial, the loss of energy in resistance and elsewhere gets greater as the oscillations get greater and will finally equal the energy put in by the alternating e.m.f. and thus stop the increase of voltage. Also, the exciting e.m.f. may slowly get out of step and so after building up the oscillations for a while, reduce them again. The increase of voltage may be stopped by a break down of insulation which may occur on account of the high voltage. That is, if we have an oscillating circuit (as, for example, a short transmission line) and an exciting cause of exactly the right alternations a very high voltage may result. The exciting cause may be either the generator e.m.f. or it may be some static e.m.f.; for example, another discharging condenser. In very few cases in actual installations, however, has it been directly shown that resonance has caused any serious rise of potential. There is no justification for hastily assigning resonance as the cause for unexplained static phenomena.

The number of complete oscillations per second in a circuit consisting of a choke coil and condenser $= 1/2\,\pi\,\sqrt{L\,C}$. So for the circuit to have a frequency of 60 cycles would require that the product of its capacity and inductance shall equal $1/(2\,\pi\,60)^2$. If the capacity equals 10 microfarads the inductance must equal 7/10 henries, which is a large value. This shows that resonance with the generator e.m.f. is very unlikely in high tension lines. A condenser of 1/10 microfarad with a coil of 1/1000 of a henry has 16,000 complete oscillations per second.

When an alternating e.m.f. is applied to a long transmission line, however, the action is somewhat different from that of a simple condenser. The first alternation of the e.m.f. sends a wave down the line which is reflected back if the end is open. If the applied e.m.f. is just slow enough so that as it starts on its negative swing, the reflected wave is just beginning to arrive again at the starting point, its e.m.f. is added to that of the impressed voltage, and a second wave of double strength is sent along the line—when the next alternation is reflected back, the applied e.m.f. has reversed and again adds to the amplitude of the wave—thus just as with a simple condenser an excessive voltage will be built up if there are no losses. But suppose that the generator has three times this frequency. The applied e.m.f. will then have the same relative value, when the first wave reaches the beginning of the line after reflection, as when it has only one-third the frequency, though two other wave crests—one positive, one negative—have been sent into the line. The amplitude of the first wave will then be doubled as before and the same with the two succeeding waves. But by this time the first augmented wave has again been reflected and reached the starting point so that it has a further increase of amplitude. The same thing occurs if the applied e.m.f. has its frequency increased to five times its original value, only five waves are operated on in a group instead of three as in the previous case; similarly with 7, 9, etc., times the original frequency (which was such that in the time of one alternation a wave would pass the length of the line and return). Resonance of this type with a long line is much more likely to be met than with a simple condenser, for there are a great number of frequencies at which resonance may occur.

If the periodicity of the applied e.m.f. is not exactly right for resonance (this applies to long and short lines), there will still be a certain amount of rise of potential which will be less as the e.m.f. departs further from the proper frequency.

A summary of the conclusions so far reached follows:

(1) When a "dead" transformer is connected to a live line a strain may be produced on the layers of the coil next to the terminal, which may be as great as the line voltage.

(2) When a short line is charged suddenly from live bus bars, a momentary voltage rise may be produced which will be not more than double voltage.

(3) When a long line is charged a strain similar to that in the short line is produced, doubling the potential first at the end of the line and afterward along the whole length. This result assumes that the charging terminal of the line is abruptly raised to full normal potential and rigidly maintained there until the wave is fully formed; also that the losses are zero.

(4) The fundamental principles governing the charging of a cable are the same as those of a transmission line.

(5) Opening a light high tension circuit may be nearly the equivalent of charging the circuit, since before the line is completely freed from the bus bars it is often momentarily recharged several times.

(6) When a branch line of small e.s, capacity is supplied from a main line, the rise of potential at the farther end may be twice as great as at the end of the main line.

(7) In addition to switching, other causes of static strains are grounding, short circuit, lightning, etc., when these cause abrupt changes of potential.

(8) A rise of potential due to resonance is always possible, but generally improbable. It requires that there be an oscillating circuit and an exciting cause which must be of very nearly the same frequency as the oscillating circuit. When an alternating e.m.f. of high frequency is applied to a long line the danger that resonance will occur is usually greatest, as it may be produced by a large number of frequencies.

Part II.—Protection of Apparatus and the Static Interrupter.

Tracing of Damage Caused by Static.

From the discussion in the first part of this paper, the conclusion seems warranted that some sort of static protection for apparatus in high tension circuits is very desirable. This fact has, indeed, long been almost universally recognized in a partial way, as is shown by the wide use of the lightning arrester. But the lightning arrester as commonly found falls far short of affording complete protection, although it has, in fact been quite effective in preventing grounds in apparatus (its only avowed object). As every person familiar with the operation of high tension electrical apparatus knows, short circuits as distinguished from grounds are a much more frequent cause of difficulty than grounds proper. Now, lightning arresters have little effectiveness for preventing short circuits, since the short circuit, when caused by static, is usually the result of the concentration on a small porton of the coil of a voltage, not necessarily great with respect to the line voltage, but perhaps very great with respect to the normal voltage of the portion of the coil where the failure occurs. Some protection, however, has frequently been secured by the use of choke coils in addition to the lightning arresters; but these have often been used in an aimless way, and have sometimes been omitted in very high tension circuits, where they are the most necessary.

The chief reason why static protection has not received more careful consideration (although the lightning arrester proper has been long in commercial use) is the very great difficulty of tracing the effects of static to their true cause. In the first place, very little is generally known as to what causes static strains and as to whereabouts in the circuit they are to be expected, or as to what sort of injuries they inflict. The direct damage from an excessive static strain is usually limited to the injury that can be caused by a spark carrying nothing but charging current to some small portion of the apparatus. Such an injury would be invisible to the eye. A great many repetitions would be required before an evident defect would appear.

In the second place when trouble develops from a static cause it is usually made manifest by an arc supported directly by the generator. This arc, of course, causes a great amount of burning of insulation and fusing of copper, which destroy all evidence of the original cause of the failure. Also at such a time usually little note is taken of attendant circumstances which could throw some light on the cause of the trouble. Most engineers will appreciate the great difficulty of getting afterwards the exact sequence of events in any breakdown. Again, sometimes a severe static strain will select some particular point where some defect in material or workmanship exists, and this imperfection when found is assigned as the cause of the failure, even though the defective part may have been amply able to withstand normal potential.

Still another fact renders the tracing of static strains difficult. Only occasionally are the conditions favorable for the exciting spark to be followed by the normal e.m.f. of the circuit, which alone makes the spark detectable. That means that if a watch is kept for the effect of any particular cause of static, such as switching, perhaps nine times out of ten this effect will not be discovered, because it is not made evident by the generator e.m.f.

Sometimes a short circuit may be started by a static spark which involves so few turns of the coil or has so much resistance that the fuses and instruments will not be noticeably affected, and nothing is known of the trouble until it has developed, which may require some minutes or some hours.

I do not mean to give the impression here that I consider every failure of high tension apparatus to be, somehow or other, due to static causes, for such is far from the truth; nor that such difficulties are of everyday occurrence, for this would be much further from the truth; but it is true that static strains do cause breakdowns, and that such are very difficult to trace to their true causes.

Protection from Static.

Protection from static is a question of growing importance, for several reasons. Circuits of high potential and long distances are rapidly extending, both as regards number, size and potential. The troubles due to static are certain to be more commonly recognized. In the future the standard of service will gradually rise and nothing threatening its interruption will be tolerated.

I propose, in what follows, to describe a system of protection of high tension apparatus from static strains that is applicable to practically all cases of high tension transmission. In actual plants difficulties from static are found to occur usually in generators, transformers or instruments, connected directly to the high tension circuits, or between lines, or to ground at ends of lines or other reflecting points. Direct strokes of lightning are an exception to the statement regarding the location of damage. Why strains should appear at these points has been already explained.

These injuries are of two distinct classes, short circuits and grounds, each type of injury being caused in a different way and requiring its own protective apparatus. They will be treated separately.

Protection against Short Circuits.

As already fully explained, static causes short circuits by producing a momentary concentration of potential (which may or may not be greater than normal line potential) upon a few layers of the coils, which very probably may have been intended to withstand only a small part of the strain brought upon them. This excessive momentary strain results from a very abrupt change of potential of the terminal or other point of the coil, either up or down. With such a change, until charge can flow to the more distant layers, the full voltage of the potential change will be impressed on the layers of the coil between the point of application of strain and those points to which charge has not penetrated. If this voltage is too much for the strength of the insulation, a spark passes. If conditions are favorable, the e.m.f. of the generator causes a current to follow, and a burnout will usually result. In some cases, however, current from the generator may start to follow and drop out at the end of the first alternation.

The characteristic of the static wave which causes the static strain to be concentrated on a few layers of the coil is its abruptness. Therefore, if this wave be forced to pass through a choke coil and its abruptness thus reduced, the strain on the coil will be lessened; if the choke coil be sufficiently powerful, the wave will be rendered harmless. It must be noted that it is by no means necessary for the choke coil to be effective, that it be made powerful enough to remove entirely the strain from the transformer coil; for the latter's insulation will withstand a much higher e.m.f. of a static nature which exists but an instant than of a continuous nature like that impressed by the generator. Also, there is usually allowed (perhaps on account of the results of previous experience with static) a very great margin in the insulation between the layers of coils.

The exact amount of abruptness allowable in the wave will depend on circumstances. Looking at the question more closely, it is seen that a choke coil cannot be said to have a definite protective power regardless of the apparatus it protects; for more choking effect is required to protect a transformer coil of many turns of layers than a coil of few. The condition to be fulfilled is that by the time maximum voltage is reached at the transformer terminal, charging current shall have penetrated far enough into the transformer coil so that a sufficient number of layers shall share the strain for their combined insulation strength to be able to resist it. The function of the choke coil is thus seen to be simply one of delaying the wave to give the inflowing charge time to become distributed over the coil. The length of time required depends on the rate at which the charge penetrates the coil and the strength of the insulation. The inductance of the protecting choke coil should be larger than that of the minimum portion of the transformer coil which is able to stand the strain of the most severe static wave that may occur.

But such a choke coil has other effects than the retarding of static waves; it will also retard the normal flow of current; in some cases to such an extent as to be quite an undesirable feature. The choke coil also has resistance and will waste energy, and unless a prohibitive cost of copper is used, this loss of energy will sensibly affect the efficiency of the plant; further, the coil will get too hot. It will be found in most cases that with high tension apparatus choke coils powerful enough to protect perfectly are impracticable on account of size or cost.

Static Interrupter.

To meet this very serious difficulty the author proposes the use of a device he has called the " static interrupter." The " static interrupter " is a combination of a choke coil and a condenser connected in such a way as to magnify the effect of the choke coil as regards static waves without causing a sensible derangement of the normal operation of the circuit. By the use of this device a comparatively small coil can be made to afford the same protection as a coil of much larger dimensions without entailing either excessive cost or excessive loss of energy or heating.

The static interrupter consists of a choke coil in series with the line and a condenser connected by one terminal between the choke coil and the winding to be protected and by the other terminal to such parts of the apparatus as have e.s. capacity with this high tension winding; in a transformer to the low tension winding and the core. However, as these parts are always (as compared with the high tension) at ground potential, the second condenser terminal may be connected directly to ground. The diagram of connections for the interrupter protecting a transformer or generator is shown in Fig. 7.

PROTECTIVE POWER OF STATIC INTERRUPTER.

It is evident that more time is required for sufficient charge to pass the choke coil to charge the transformer terminal and condenser together than would be required to charge the terminal alone. This means that the maximum static strain will be distributed over a larger number of layers in the first case than in the second. The ratio of the e.s. capacity of the condenser to that of the transformer terminal and the adjacent parts of winding is an important factor in determining the protective power of

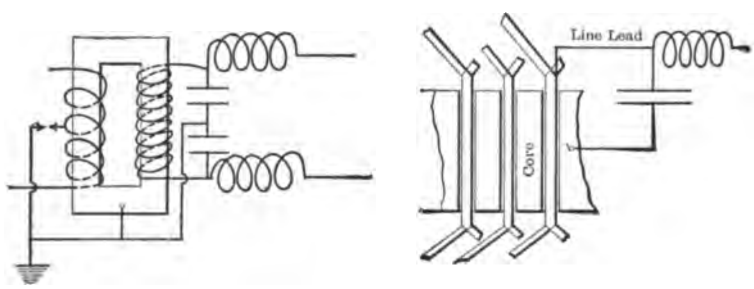


FIG. 7.—Static Interrupter Protecting a Transformer and High Tension Generator.

the interrupter, as it indicates the extent to which the potential of the terminal at any instant is reduced by the addition of the condenser. It is possible to get almost any desired degree of protection by the use of a sufficiently large condenser without unduly increasing the size of the choke coil in series with the circuit. Actual experiment shows this method of protection to be very effective in reducing the static strains in coils.

On the other hand, the use of the static interrupter, although it delays the penetration of the crest of the advancing static wave, does not necessarily prevent the ultimate rise of potential of the terminal, that is, it affords no direct protection against grounds. However, in cases where the interrupter is used in connection with a lightning arrester (which should always be connected on the side of the choke coil farthest from the condenser) the delay of the wave does give additional protection against grounding of the winding, as it allows the arrester more time to discharge the line.

The interrupter performs a more important function in connection with the discharge of an arrester by protecting the winding from the violent strains that result from the abrupt grounding of the circuit caused by the discharge. As the discharge of the arrester occurs only when line potential is much above normal, and may be carried momentarily much beyond ground potential on account of its oscillatory nature, the shock to the coil may be a very severe one.

Location in Circuit of Static Interrupters.

It is thus evident that by placing a proper static interrupter in each lead wire of a transformer or other apparatus which may be connected with a source of static disturbance such as a line or a high tension switch, complete protection may be secured against short circuits in the windings caused by static originating outside of the transformer. As switching is a frequent cause of static strains, the interrupters should in general be placed between the apparatus and the switches thus making the interrupter virtually a part of the transformer or generator to be protected and not a part of the line. If, however, each individual transformer is provided with static interrupters a larger number of interrupters is required than would be necessary for protecting a bank of transformers as a whole from disturbances upon the transmission line. If there is no switching of individual transformers it is then satisfactory to arrange the apparatus so that several transformers will be protected by the same interrupters. For example, in polyphase systems, a group may be protected as a unit instead of giving individual protection to each transformer. The precise arrangement of apparatus in a given case will depend upon the number of transformers to be protected and the arrangements which are provided for switching.

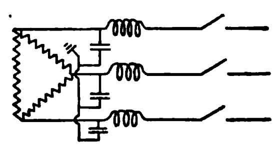
There are certain cases in which switching may be done between the interrupter and the transformer. The transformer may be cut out of circuit by the opening of circuit breakers, fuses or switches, or transformers may be connected to a live high tension circuit, provided their low tension windings are at the time supplied with current from the same generator as the circuits from which they are switched. Such switching causes no change of potential at the terminals and consequently no strain.

Also fuses and circuit breakers may be opened by overloads or short circuits without regard to the low tension connections or without danger from static as the arc formed assures a gradual change of potential.

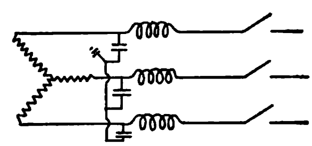
The proper connections for static interrupters in the arrangements of apparatus most frequently found are shown diagrammatically in Fig. 8.

FEATURES OF COMMERCIAL STATIC INTERRUPTERS.

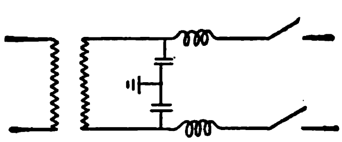
Some of the features of actual static interrupters intended for commercial service work may be of interest. These interrupters



Three Static Interrupters Protecting Three Transformers Connected in Delta.

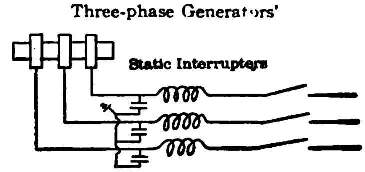


Three Static Interrupters Protecting Three Transformers Connected in Star.

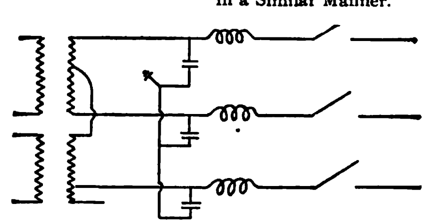


Two Static Interrupters Protecting One Transformer.

Three-phase Generators'



Three Single Pole Static Interrupters Protecting a Three-phase Generator.
Single-Phase and Two-Phase Generators are protected by Two and Four Single Pole Static Interrupters Respectively, Connected in a Similar Manner.



Three Static Interrupters Protecting Two Transformers Connected for Three-Phase High Tension and Two-Phase Low Tension Circuit.

FIG. 8.—Diagram Showing Arrangements of Static Interrupters Protecting Generators and Groups of Transformers.

are usually single pole; that is, one coil and one condenser are placed in a containing case. As the interrupters are used on high voltages, coils and condensers are placed in oil. The oil facilitates the cooling as well as strengthening the insulation. The choke coils, which contain no iron, receive the full force of the static waves which they are intended to check, and are very heavily insulated. On a three-phase circuit the condensers must support continuously a strain approximately 6/10 of the normal line voltage without breakdown and without overheating; they must also be able for moderate lengths of time to stand full line voltage in case one leg of the circuit becomes grounded.

The fact may not be generally appreciated that condensers have a very considerable heat loss which must be carefully considered in designing the interrupter. This loss for any given dielectric varies in actual condensers approximately as the square of the voltage, and increases rapidly with the temperature. The loss in a condenser may be increased several times by changing its temperature from 20° C. to 100°C. This fact indicates the importance of not allowing condensers to get hot.

The actual e.s. capacity of condensers for static interrupters is made much larger than the e.s. capacity of the windings they are to protect, but is still very small—seldom exceeding a few hundredths of a microfarad. The reaction of the condenser upon the circuit for generator frequencies is therefore negligible.

At the end of this paper are shown some views of a static interrupter for 50,000 volts, 19 amperes.

Protection Against Grounds.

A ground is the result of a rise of potential higher than the insulation of the apparatus is adapted to withstand (assuming that the insulating material contains no local defects). Such an excessive strain may result from static disturbances or from other causes. It has been shown that lightning may be one cause, and that under certain circumstances switching and similar disturbances may produce high momentary voltages. Therefore, unless the apparatus is insulated to stand such excessive potentials, which may be possible with low and moderately high voltage circuits, but is hardly practical with extra high tensions, we must use some means of prevention. The standard lightning arrester spark gap used to prevent excessive potentials from lightning is effective also against the other static causes.

Lightning Arresters.

A simple air gap between line and ground is an ideal lightning arrester or line discharger as far as its protecting power is concerned. It absolutely resists the passage of current up to a certain voltage, which can be predetermined quite closely, and if this critical voltage is exceeded, breaks down and furnishes a non-inductive and nearly resistanceless discharge path for carrying off any amount of static electricity that may appear on the line. This means that when once the gap has broken down no amount of charge on the line can raise its potential above the ground. However, if the ground connection be not perfect or if either in the arrester or in its connections there is sufficient inductance or resistance, it is then possible to have a dangerous rise of potential on the line after the air gap has broken down due, of course, to the checking of the discharge of the line by the inductance or resistance.

Unfortunately, however, when single spark gaps are used as lightning arresters, their simultaneous discharge on two or more legs of a line forms a short circuit, and the usual result follows. If one leg of a circuit is accidentally or permanently grounded an arrester discharge on any one of the other legs causes a short circuit.

The air-gap lightning arrester to be commercially successful, in addition to giving protection from static must be able to interrupt the short circuit current which tends to follow lightning discharges. The devising of an arrester to meet all conditions is a very difficult problem. Fortunately, however, a large number of small gaps in series may be substituted for one single gap of larger dimension which greatly increases the "non-arcing" power. A very few gaps of non-arcing metal are satisfactory under some conditions; but the more the gaps are sub-divided the more effective the arrester. On high voltages, however, and under some other circumstances, such a large number of these gaps must be used on the arrester, as to interfere with its protective power by requiring a rather excessive voltage to cause the gaps to discharge. If the amount of the current that can flow on short circuit be limited either by series resistance or otherwise, a considerably less number of gaps will be non-arcing.

Series Resistance.

The use of series resistance to render an arrester non-arcing has the advantage of cheapness and simplicity, and is very effective as far as rendering the arrester non-arcing is concerned, but it has the great disadvantage of introducing the resistance in the path of the discharge of the line. In many plants the small size of the generators limits the current flow on short circuit in such a way as to render no series resistance necessary. It must be remembered in this connection, that all synchronous apparatus connected to an electric circuit (and sometimes induction motors), will temporarily act as generators at the time of a lightning discharge, on account of the energy stored in the momentum of their revolving parts.

In many cases where the short circuit current taken by the arrester is not excessively large, the series resistance may be shunted by additional gaps which will allow the static discharge to pass directly to earth around the resistance. If the parts are properly proportioned, the subsequent arc will be drawn from the shunted gaps by the resistance and thus extinguished. If the number of shunted gaps is no greater than of the unshunted gaps, no greater voltage will be required to discharge over the whole number than over the unshunted gaps alone. This is because the shunted and unshunted gaps are separately broken down—one after the other. Therefore, no protecting power is lost by the addition of the shunted resistance.

In the cases where such resistance, shunted by gaps, is not sufficient, a small series resistance in addition will make the arrester non-arcing. In other words, where a large series resistance is required, part of it may be shunted by gaps in such a way as to introduce only a small resistance in the discharge circuit of the arrester.

It should be noted, as in the case of short circuits in coils from static sparks, that if the discharge through an arrester passes at or near the time of zero e.m.f. of the generator, there will be little likelihood of a permanent short circuit.

Although the insertion of resistance in the discharge path of an arrester may under some circumstances prevent the very thing that the arrester is supposed to accomplish, nevertheless its great effectiveness in rendering the arrester non-arcing and its wide commercial use requires a statement of the conditions under which it may safely be used. It evidently makes no difference how much resistance or inductance is used in series with an arrester, provided it is always able to discharge the electricity as fast as it actually appears on the line at the point where the arrester is connected, without causing a potential in the arrester greater than that required to cause the arrester to discharge in the first place. In discharging electricity, a resistance requires a potential equal to the product of the current strength and the resistance; inductance causes a counter e.m.f. equal to the product of its inductance and the rate of increase of the current. At each instant of time the current flowing in the arrester circuit has a definite value and a definite rate of increase (or decrease). Therefore, for the arrester to meet the above condition, the sum of the two potentials caused first by the current at the moment flowing in the resistance and second by the rate of increase of current in the inductance, must at no time exceed the potential required to cause the arrester to discharge.

It will be readily seen that the greater the quantity of static electricity to be discharged and the more sudden its appearance, the more severe the conditions on the arrester. Also that the greater the resistance and the inductance of the arrester circuit the greater the likelihood of a dangerous rise of potential, Just what the greatest allowable values of resistance and inductance are in any given case will depend upon various circumstances and cannot usually be definitely predicted. Therefore, in all cases the lowest practicable amount of resistance and inductance should be used in series with the discharge path of the arrester. It should be noted that with an increasing current flow through the arrester circuit the quantity of electricity discharged by the arrester before the dangerous point of potential is reached will be much more than proportionally greater with a low than with a high resistance. That is, if the series resistance in one case is one-half that in another, both discharging the same increasing current, the quantity of electricity that will have passed the first arrester when a given potential is reached is much more than twice that passed in the second case, when the same potential is reached. This fact makes it still more desirable that series resistances should be kept as low as possible.

Resistance and inductance in series with the arrester circuit have the advantage of preventing to some extent the very sudden grounding of the line that otherwise results from the arrester discharge and which causes severe strains in the windings of adjacent apparatus. This is an advantage by no means to be overlooked, for it will be remembered that short circuits are much more frequent than grounds.

Location of Arresters.

A proper air gap lightning arrester will prevent an excessive rise of potential above the ground at that point of the line to which it is connected, but on account of the wave nature of the static disturbances it will not necessarily prevent an excessive rise of potential at some other point of the circuit more or less distant. For if the arrester happen to be at the zero point of a wave, the arrester will not discharge, even though the crest of the wave at some other point may be at a very high potential above the earth.

It is a somewhat difficult problem to obtain complete protection at all points; however, in actual circuits adequate protection can usually be secured. Actual commercial plants fall into two classes, viz.: plants in which the apparatus connected to the high tension circuits is scattered about at numerous more or less widely separated points, and plants where the apparatus is all concentrated at a few points.

(*a*) PLANTS WITH APPARATUS DISTRIBUTED.

For absolutely complete protection from ground in plants having distributed apparatus, arresters will have to be placed wherever there is apparatus that needs protection. In most cases this would mean an almost prohibitive expense. Fortunately such plants are ordinarily of comparatively low voltage, and therefore require protection (as far as static from grounds is concerned) only from lightning. Therefore, by placing arresters in such locations as readily to discharge static waves that may arise in the most exposed portions and by scattering arresters at intervals over the line at other points sufficient protection is secured. The exact number of arresters required in any given case depends upon the local conditions. This type of circuit, with distributed apparatus, is seldom found above 3,000 volts.

(*b*) PLANTS WITH APPARATUS CONCENTRATED AT A FEW POINTS.

In these cases the sources of static disturbance are either at some point away from the apparatus or are, electrically speaking, at the point where the line enters the station; that is, when a rise of potential is caused by switching in the station, all the high tension wiring is at the same potential and the rise can be limited by an arrester placed on each leg of the line at the point where the line enters. But these arresters, provided they be placed on the line side of apparatus, will also protect from dangerous static waves produced at points away on the line, for such waves must pass the arrester before they can reach the apparatus, and will thus cause the arrester to discharge. Therefore, in circuits of this type, which includes practically all high tension circuits, protection from grounds will be secured by proper arresters, placed one on each line wire where it leaves a station. The arrester must be placed outside of all choke coils and static interrupters, so that these may prevent static strain in the apparatus from the discharge of the arrester. This distribution of arresters is the one that has usually been followed in actual installations.

The system of protection outlined for high tension circuits, therefore, consists of the use of proper lightning arresters at appropriate points to protect against grounds, and static interrupters to protect apparatus against short circuits. The lightning arresters should be of adequate design, but no radical change from the usual practice in regard to location is required.

The use of the static interrupter is, however, new, and it has been one of the objects of this paper to give a full exposition of the protection it affords and to discuss carefully the conditions which render its use advantageous.

Summary.

A summary of the most important conclusions regarding arresters and interrupters follows:

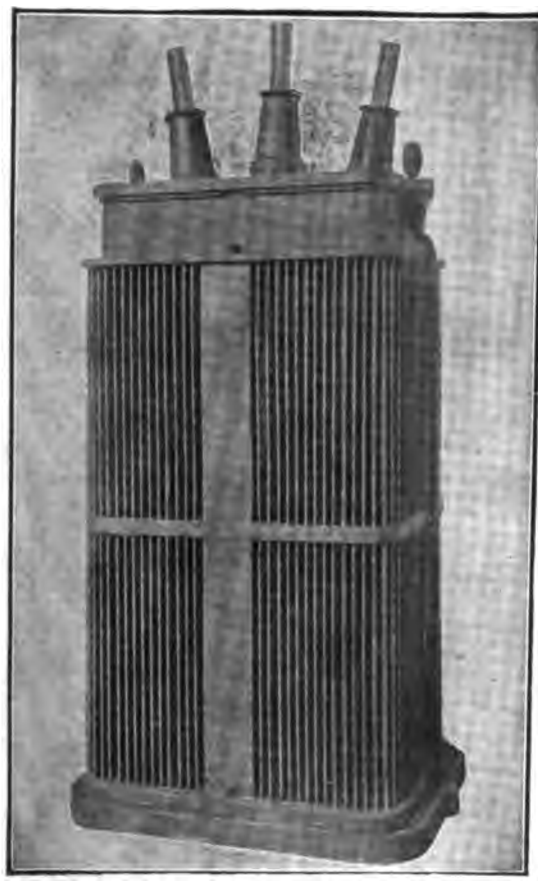
(1) Damage resulting from static strains is of two sorts: short circuits and grounds. It is the function of the static interrupter to protect apparatus against short circuit strains; it is the function of the lightning arrester to relieve the line of excessive static charge and thus prevent grounds.

(2) The static interrupter consists of a choke coil and condenser, the latter being connected between line and ground on the apparatus side of the choke coil. The interrupter delays and smoothes out static waves which attempt to pass it. The condenser, by absorbing a large part of the static charge which passes the choke coil, very much increases the effectiveness of the coil.

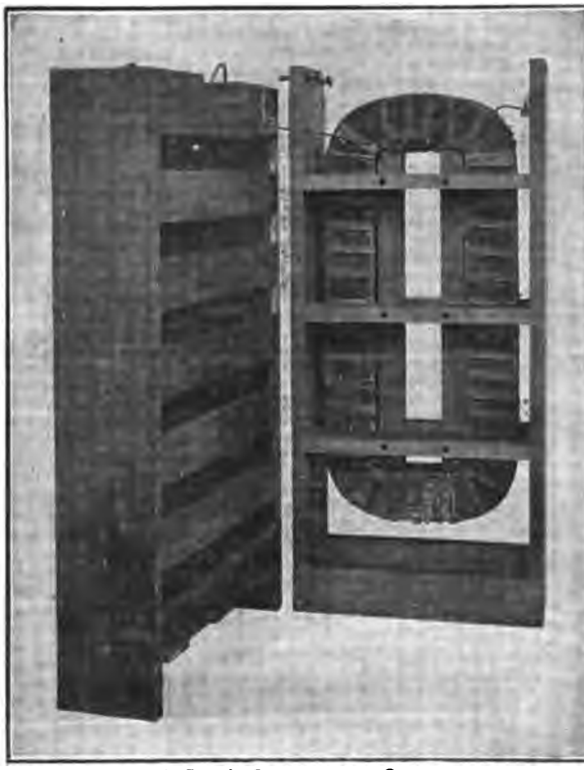
(3) The choke coil and condenser of the interrupter must be adapted to the circuit upon which it is to be run, and must be proportioned with regard to the design of the apparatus it is to protect. The interrupter should be placed nearer the apparatus than any switches which are to be operated with potential on the line. (See page 147 for exceptions.) The interrupter is thus essentially a part of the apparatus to be protected and not a part of the line or the arrester.

(4) Lightning arresters must be able to discharge electricity from the line as fast as it actually appears there, and must also be non-arcing under all conditions. Any resistance or inductance used in series with the arrester should be low enough to allow the passage of all actual discharges without causing excessive potential on the arrester.

(5) On the systems where the apparatus is distributed the arresters should also be distributed.



Static Interrupter with Case Complete.



A Static Interrupter Open.

View of Static Interrupter from the Top.

On systems with apparatus concentrated at a few points arresters should be placed on each line wire where it leaves a station.

(6) Well designed static interrupters and lightning arresters, properly arranged, furnish a complete system of protection against the static disturbances found on high tension lines.

It is quite evident that the protection of the apparatus of a large high tension system, with its numerous opportunities for static disturbances and its widely spread apparatus, is by no means a simple problem, to be solved off-hand by the use of a few lightning arresters of any available style. The type and location of the protective devices must be adapted to the actual conditions of the plant; the severity of the lightning in the neighborhood, the voltage of the system, the type of apparatus to be protected and perhaps the actual constants of the circuits. The determination of the most satisfactory protection is a matter to be arrived at from a combination of theory, experience and experiment, and any protective system should be freely modified when actual trial shows a better arrangement. It is to be hoped that engineers and others who have the opportunity will carefully study experimentally the questions of static, giving them all the attention that their importance deserves, and that we may in consequence look forward to the time when difficulties from static causes may be practically unknown.

Appendix I.

EXPERIMENTS ILLUSTRATING LOCAL CONCENTRATION OF POTENTIAL IN A HIGN-TENSION COIL.

Shown at the meeting of the Institute, February 14th, 1902.

To illustrate the effect of switching short-circuits and lightning in producing local concentration of potential in coils connected to a transmission line, experiments were performed as follows:

1. *Effect of Switching—Charging a Dead Transformer from a Live Line.*—The arrangement of the apparatus is shown in Fig. 9.

A 30 k.w. 30,000 volt raising-transformer was used to charge the line. The electrostatic capacity of the line is represented by a pair of oil condensers (*c. c.*) connected in series with their common terminal grounded. Each of these condensers had a capacity of approximately .012 microfarads. The ratio of transformation of the raising-transformer was such as to give approximately 25,000 volts on the line.

The transformer coil was a single coil of 52 layers surrounded by a heavily insulated metal plate D, which represented the low tension winding and the core. This coil was taken to be the coil of a lowering-transformer lying next the terminal at which switching was to be done. The remainder of the transformer, which is permanently connected to the other line, is replaced by the high resistance R, which serves to support the line voltage when the circuit is closed.

The blunt-nose spark-gap P was used to measure the maximum instantaneous voltage on different parts of the coil caused by switching. Leads were brought out at various points in the coil to facilitate this measurement.

In the experiment the switch A was closed and opened repeatedly until the measuring spark-gap could be so adjusted as to indicate the maximum instantaneous voltage caused by closing the switch; this point was indicated when the gap would break down

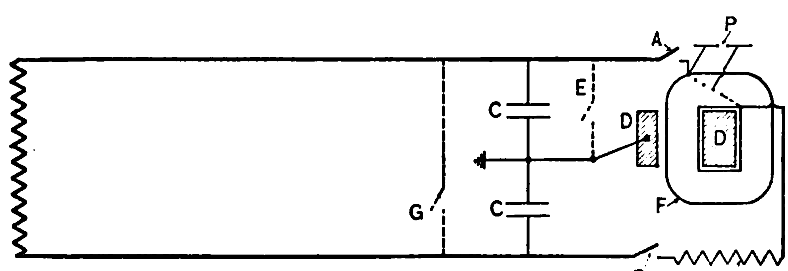


FIG. 9.—Diagram of connections to show effect of charging dead transformer and effect of short circuits.

once or twice only in 50 trials. A large number of trials is always necessary, as the closing of the swing-switch does not always occur at the point of e.m.f. wave most favorable for causing a high potential.

By this means the maximum potential between the terminal and the 4th, 8th, 12th layers, etc., was successively determined. The results are plotted in a curve in Fig. 10. The normal voltage that would exist on a layer, were the coil in an actual transformer, is something like 75 volts. The maximum potential reached *between the lines* during switching was approximately 33,000 volts. This is a very considerable increase over the 25,000 volts of the line, and represents the rise of potential usually accompanying the charging of a condenser through inductance. It is evident that very great strains are produced by the switching on the layers next the terminal.

2. *Effect of Short Circuits.*—The same apparatus was used, and with the switch A closed, the line was repeatedly short-circuited by a switch connected at G. Measurement of potential on the various layers of the winding, made in exactly the same manner as before, gave voltages approximately one-half of those due to switching, shown in Fig. 10. As the change of potential of the terminal in the case of short-circuiting is only one-half of that caused by charging the dead transformer, only half the instantaneous rise of potential is to be expected.

3. *Effect of Lightning.*—The apparatus of the test which is very similar to that used in the above experiments is shown in Fig. 11. The condenser represents the electrostatic capacity between a charged cloud and the line, and the closing of the switch H the discharge of the cloud. This arrangement is not strictly analogous to the effect of lightning on a line, as dynamic induction

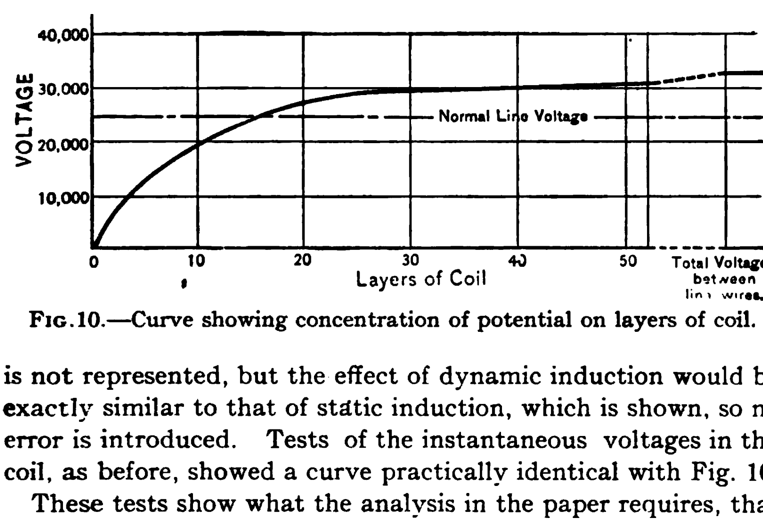


FIG. 10.—Curve showing concentration of potential on layers of coil.

is not represented, but the effect of dynamic induction would be exactly similar to that of static induction, which is shown, so no error is introduced. Tests of the instantaneous voltages in the coil, as before, showed a curve practically identical with Fig. 10.

These tests show what the analysis in the paper requires, that abrupt static changes cause a local concentration of potential near the terminals of the coils, the amount of which depends simply upon the abruptness and severity of the potential change.

To illustrate the protective power of choke coils and static interrupters experiments were performed as follows:

1. *Choke Coils.*—Three choke coils were used, all having a mean length of turn about two feet. The first had 80 turns, the second 352 turns, the third 1,200 turns. With the coil of 80 turns placed in the lead of transformer coil next to switch A, the instantaneous voltage on the first four layers, which was caused

by switching with no coil in the lead, was cut down about one-third. But this coil had no appreciable effect on the instantaneous voltage on the first 30 layers, showing that a few layers of the transformer coil may be much more easily protected than many layers.

With the coil of 352 turns connected in the lead, however, the voltage on the first 30 layers was cut down to nearly one-quarter its original value. With the coil of 1,200 turns the abnormal voltage was cut down to less than one-tenth of its original value. Thus the effectiveness of a choke coil in reducing the short-circuit strains is clearly demonstrated.

2. *Static Interrupters.*—It had previously been shown, as described above, that the choke coil of 80 turns could not appre-

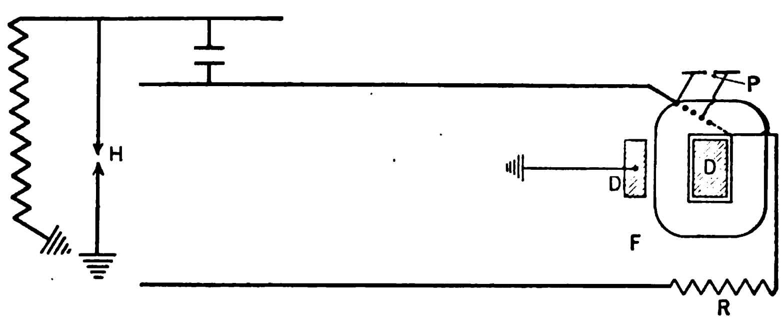


FIG. 11.—Diagram of connections to show effect of lightning.

ciably lower the instantaneous voltage on the first 30 layers of the transformer coil. When, however, a condenser of less than .0015 microfarads capacity was added, so as to form a static interrupter, this abnormal e.m.f. was reduced nearly 50 per cent. and with a larger condenser was cut down to approximately one-quarter of its original value. A still larger condenser would have practically removed the abnormal potential altogether. Or if the voltage in the first 15 layers had been measured, instead of in the first 30, it would have been found a few per cent. of its original value.

It is possible by properly proportioning coil and condenser to get any desired reduction in the abnormal voltage on any desired number of layers.

APPENDIX II.

MECHANICAL MODEL ILLUSTRATING THE PROPAGATION OF STATIC WAVES IN A LONG TRANSMISSION LINE.

Exhibited at the meeting of the INSTITUTE, February 14, 1902.

To illustrate the propagation of static waves in a long transmission line, such as result from abrupt changes of static potential, the mechanical model described below was exhibited. A long transmission line (or cable) may for all practical purposes be represented by a series of choke coils and condensers as in Fig. 1, page 119. The law governing the currents, charges and e.m.f.'s in this circuit may be stated as follows: At any instant the difference in potential between any two neighboring points is equal to the e.m.f. consumed by the passage of the current through the resistance of that portion of the line wire between the points, added to that consumed in the back e.m.f. due to the inductance of the line between the points. If any mechanical device can be found, such that the same law will govern the motion of its parts, then exactly the same sort of waves will be produced in one case as in the other, provided appropriate forces are applied. The model exhibited, which is shown in the cut, Fig. 12, is such a device.

Referring to Fig. 1, page 119, the condensers representing the capacity to ground at the points B, C, D, etc., are replaced in the model by the springs seen near the top of the frame. The condensers representing the capacity between line wires are replaced by the springs shown near the bottom of the model. These springs are not so large as the first, as so much extension is not required. There are two sets of springs of both sizes, indicating the two line wires; one set is hung on the front of the frame, the other on the rear. The inductance between two adajcent points of the line is represented by the inertia of the lower line of pulleys, which are controlled by the small springs. These wheels are made thick to give them mass. The springs representing capacity and the heavy wheels representing inductance are connected together by an endless thread which serves the function of a conductor between points. As this thread must move freely it is carried on pulleys; it must not slip, however, on the heavy pulleys. The resistance of the line is represented by the friction of the wheels and the stiffness of the thread. It must be noted here that the model is not strictly analogous to the electric circuit in this respect, for its friction is not strictly proportional to the velocity of motion, as it should be, since the loss of e.m.f. due to resistance is exactly proportional to the current. However, as the friction is relatively small, the movements of the model are almost wholly controlled by the springs and the inertia; the resistance simply causes a dying out of the waves.

The two divisions (front and back) of the model representing the two line wires are connected together through the heavy wheels at the bottom, which are rigidly linked in pairs by cords running over stationary pulleys. A motion upward of one heavy wheel means an equal motion downward of its mate. That is, equal positive and negative charges must appear simultaneously in the two transmission wires. As the lower springs represent the capacity between the line wires, their extension measures that part of the total line charge due to this capacity, and at the same time indicates the voltage between lines. Similarly, an extension of the upper springs indicates that portion of the total line charge due to the capacity to ground, and, as well, the potential rise above the earth. Motion or displacement of the thread which runs over all the pulleys indicates quantity of electricity. Velocity of motion represents current strength. Force or tension on the cord represents e.m.f. and the device used for producing this force, the generator. The cord runs from one line to the other through the generator, so that whatever current flows out at one terminal must flow in at the other. To represent the lines short-circuited, at the farther end the cord passes freely from one line to the other. To represent an open circuit in the line at any point, it is necessary only to hold the thread rigidly at the point where the open circuit is supposed to exist, so that no electricity can pass. Then, releasing the thread is the equivalent of closing the open circuit.

The generator consists of a pulley carrying the endless thread supported by two loops of cord running in proper grooved wheels, as shown at the right in Fig. 12. These loops or belts hang on a revolving rod driven at a high rate of speed by a motor, so that they slip continuously on the rod. The pulley and grooved wheels, which are fastened rigidly to the same shaft, are free to turn by the slipping of the belt. The friction of the belts on the revolving rod causes a constant torque on the pulley carrying the thread, and consequently on the adjacent parts of the line. This torque acts as an e.m.f. As the rod supporting the belts revolves at a very high rate of speed, the comparatively slow motion of the driving pulley hanging below will not materially affect the friction. Therefore, the e.m.f. is constant regardless of the " current " flowing (that is, regardless of the velocity of the thread. The amount of the e.m.f. applied is varied by hanging weights on the driving pulley to increase the friction of the slipping belts on the supporting rod. These weights must, of course, be supported through bearings in which the driving pulley may revolve.

In the model, the energy stored in capacity is represented by

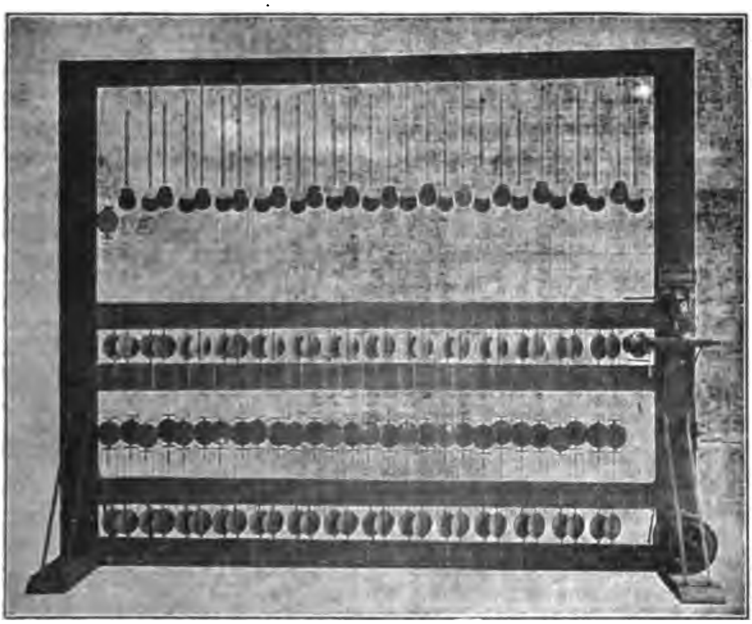


FIG. 12.—Mechanical Model of Transmission Line.

the energy stored in the stretched springs; and the energy stored in the inductance is represented by the kinetic energy of the revolving pulleys. When a steady direct-current flows through the line storing magnetic energy in its inductance, all the wheels have a constant velocity and a constant kinetic energy

The following well-known phenomena in a transmission line were illustrated by the model: Charging a dead open-circuited line; short-circuiting a charged line at the farther end; opening a short-circuit at either end; ohmic drop in the line; energy stored by direct current in the short-circuited line.

Several seconds are required for a wave to pass the length of the model and return, The length of time required depends on the moment of inertia of the wheels and the elasticity of the wheels. Each heavy wheel weighs six ounces and is approximately 5½″ in diameter. Each of the large springs has such an elasticity as to extend 26″ under the weight of one-half pound. The small springs extend 10″ under the same strain. It is important that the friction be made as small as possible.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

NEW YORK, Feb. 14, 1902.

The 161st meeting of the INSTITUTE was held in Havemeyer Hall, Columbia University. President Steinmetz called the meeting to order at 8.45 P.M.

PRESIDENT STEINMETZ:—Gentlemen, Members of the Institute and Guests: I hereby open the 161st meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Before giving the floor to the speaker of the evening, I desire to make the announcement that, by the courtesy of the University authorities, the engineering department and the engineering building have been thrown open to-night to visitors, and that you will find attendants there to show and explain all interesting features to those who desire to see them.

I now call upon the speaker of the evening, Mr. P. H. Thomas, for his paper on "Static Strains in High Tension Circuits, and the Protection of Apparatus."

[Mr. Thomas read his paper. See **page 213.**]

PRESIDENT STEINMETZ:—Gentlemen, we have listened to a very interesting paper, and I believe I voice your sentiment when I say that we are all very thankful to the speaker for giving us this clear exposition and experimental demonstration of the phenomena of electrostatic disturbances in high potential lines. Discussion is now in order. Perhaps Mr. Scott will say a few words regarding these phenomena, which he has undoubtedly studied very thoroughly also.

MR. C. F. SCOTT:—Mr. President, I do not care to enter into an extended discussion of the subject which has been so well presented by Mr. Thomas. There are, however, a few thoughts of a rather general nature to which we may well give a moment's attention. A purely mathematical investigation has little interest or little value, except as a mathematical exercise. On the other hand, a purely experimental investigation, which does not connect itself with the underlying theory is something of interest, but as it is independent of other things, it has not a great deal of value. When the two are combined, when the and experiment can go along together hand in hand, results of value and importance may be obtained. Nevertheless, unless these results have some practical import and some useful end they are not of very great value, although they may be of interest. What Mr. Thomas has presented to us combines the three things. A sound theoretical basis, intelligent and painstaking experiment and useful and important results.

I have been very much interested during the last few years while Mr. Thomas has been carrying on his work to note the steps by which he has progressed. One day he would present a formula, something that he had found in some book, or had worked out himself, and that had some bearing on the subject. A few days later he would say that he had made experiments which showed that the formula was all right and he had demonstrated it, but he had found something else that he could not understand, in his experiments, and he then proceeded with his x's and y's and the long S's, (as some persons term integral signs) to predict new things which were then tested in the laboratory. So I think we may commend the paper as being the result of the right kind of scientific and experimental work, that which uses theoretical formulæ and the conclusions of others and applies them in a new field, which is explored experimentally, and then produces useful and important results.

PRESIDENT STEINMETZ:—I now call upon Mr. Blackwell to give us the benefit of his very wide experience with high potential transmission lines, or long-distance power transmission.

MR. F. O. BLACKWELL:—I think the INSTITUTE is to be congratulated upon the beautiful exposition of high potential phenomena which Mr. Thomas has shown us. I recall some magnets in which the exciting current had to be frequently opened. A condenser in shunt across the coils absorbed the kick and eliminated the arc at the switch. The principle is much the same as that on which Mr. Thomas's experiments are based.

There are some other causes of high-tension oscillations which might be mentioned. I have noticed often in making a high potential circuit, we get a discharge over lightning arresters which does not occur in interrupting it.

The use of much reactance in series with a transmission line to force lightning into a discharge path might produce serious results. This is very marked with " Y " connected three-phase transformers on transmission lines of high capacity. I remember with this arrangement of transformers connected to an open circuited 30,000-volt line 70 miles long, that an arc jumped across transformer terminals a foot or more apart, representing a tremendously high potential. The insulation in the transformer itself was perhaps a quarter of an inch thick and it seems strange that it should not have been punctured. This brings up another point seldom considered, that is, the ability of the best insulating materials to stand instantaneous applications of high potential. We know in testing high-tension transformers that they do not break down under two or three times the potential which they are designed for and yet our tests compared with lightning are of long duration. It would seem, therefore, as if the transformers built for the high voltages now used were pretty well insulated against lightning. At least, that has been my experience. Where lightning has injured such transformers it has usually been by jumping from the terminals of the transformer to the case, rather than through the windings.

Short-circuits between turns are much more frequent than grounds, and to prevent such troubles Mr. Thomas's static interrupter will be of great value.

MR. H. W. FISHER:—As impulsive rises of voltage are mostly determined by measuring the length of the spark gap, and as the ordinary methods of doing this do not give very satisfactory results, I think it is opportune that a little time be spent in discussing this very important subject. Our society has furnished us with an excellent curve of spark distances, but it has not laid down any laws for the conditions under which spark distances may be determined with accuracy and uniformity.

There is a tendency now to measure voltage by means of the sparking distances, reference being made to the AMERICAN INSTITUTE curve, and the results obtained are apt to be misleading and inaccurate on account of the varying e.m.f. curves of the testing set, and also on account of conditions under which the spark distances may vary considerably for the same voltage. I will touch briefly on this all-important subject, pointing out some of the conditions under which varying spark distances for given voltages occur, and also mentioning conditions under which the spark distances are much more uniform.

About twelve years ago, realizing the important bearing that this subject had on high voltage testing of underground cables and the determination of disruptive rises of voltage, I began a great variety of tests which have been continued at intervals ever since.

I found that while for e.m.f.'s of 1,000 volts or thereabouts that the sparking distance was longer between very sharp points; this was not necessarily the case when the e.m.f. reached 6,000 volts or over, and for 1,000 volts between rounded surfaces I found that the spark distances might be as small as .002 inch, while between the sharpest needle points the distance became .0045 inch, the distances for blunter points lying between these two limits.

By means of a microscope and a grating having 100 lines to the millimetre, I measured and classified the diameters of the points of the sharpest needles obtainable and found that the sparking distances would hardly vary 1-1000th of an inch between points of the same diameter.

By means of electrolytic methods, I made metallic points which were still sharp under a magnifying power of 600 diameters and between points of this character the sparking distance was about .055 inch. It is generally found that the sparking distance curve for e.m.f.'s running up to 10,000 or 15,000 volts is practically a straight line above 3,000 volts, and that this straight line does not pass through the origin but is slightly on the voltage line side of it. This apparently means that a considerable voltage is required to spark through a very small distance, and the reason for this is on account of the resistance offered by condensed air, a film of which is supposed to be on all surfaces. For the lower voltages, therefore, the spark distance curve is no longer a straight line, but it approximates more nearly to one, the sharper are the points used, and I firmly believe that if we could use mathematical points, the spark distance curve would be a straight line passing through the origin. With the points which I constructed I came within .002 or .003 inch at 1,000 volts of reaching the straight line passing through the origin to which I referred above. An explanation of the above would seem to lie in the fact that an infinitely sharp point could contain no condensed air and hence the resistance to an electric discharge would be reduced to a minimum. Based on these facts, it is evident that in measuring low voltages sharp and uniform points should be used.

With 6,000 volts I found that the spark distance could be increased as much as 25% by filing a very little off the point. Whether this action momentarily removes the condensed air from the surface of the points and thus increases the spark distance, or whether for such voltages a definite radius of curvature or form of point gives a maximum spark distance I cannot tell, but I am inclined to the latter belief.

On account of the irregular results which therefore may be obtained by slightly abraded points, it is essential that for all voltages we should use uniform points, and I have always obtained the best results with very sharp points.

Having thus spoken briefly on the effects of different kinds of points, I now come to what I consider one of the most important things that lead to discrepancies and inaccurate results, viz: Brush discharges tending in an outward direction which take place between needle points. I have studied these discharges a great deal, and I believe that they are caused by surges which are not sufficiently great to affect the average voltage.

When needles are subjected to a high voltage, the points become luminous and suddenly very small discharges may be noticed to begin in a slightly outward direction. The points of these discharges begin to move back and forth as though affected by resonance and at the same time they reach out further and further toward each other from opposite needle points. If the points of the discharges happen to come together, an arc will immediately take place between the needle points. If they do not come together they may become less and less, and finally disappear, to reappear a moment later. These discharges are the cause of great irregularity in measuring spark distances and for e.m.f.'s of 40,000 or 50,000 volts I have obtained as much as one-half inch difference in the spark length for the same measured e.m.f., the tests being made one after the other and with needle points the diameters of which had been measured and classified. In order to get more nearly uniform results, I devised a plan to use metallic disks slightly at the back of the points, the idea being that by this method the points would be shielded, a tendency to brush discharge occurring at the edges of the disks. Under these conditions I obtained much more uniform results but unfortunately on account of the construction of my sparking apparatus I was unable to use disks greater in diameter than two inches and I believe for 40,000 or 50,000 volts the diameter of the disks should be 5 inches or 6 inches; however, at 40,000 volts the results which I obtained were much more nearly uniform than before, and for 20,000 they were extremely uniform. I believe that by some such plan as this, maximum voltages could be determined very accurately by means of the spark distance, and I would very much like to see the INSTITUTE take up this matter fully and publish methods which can be adopted over the country at large and which can be relied upon to give excellent results. I expect to continue my experiments, and hope to be able to contribute something more at a later date.

PRESIDENT STEINMETZ:—Gentlemen, the only statement I can make is to relate some experience I had with these phenomena. Last summer I had occasion to make some experimental investigations on a long-distance transmission line of very high potential at Kalamazoo. I had at my disposition two three-phase lines of 22 miles length, which doubled up gave a total effective length of 44 miles, using for half the distance two wires in multiple. The measured resistance of the line was 140 ohms; the inductive reactance at 60 cycles was 220 ohms (calculated); and the capacity reactance at 60 cycles was 6,000 ohms. The reason for choosing this line was that while operating normally at 25,000 volts, it was unusually well insulated, with line wires a distance of 42 inches apart, so that I felt confident that by series-connecting the step-up transformers I could safely operate this line at a potential of 40,000 volts and still have sufficient margin not to break down under electrostatic stress, and indeed by oscillograph I observed instantaneous peaks of potential exceeding 120,000 volts without causing a breakdown of the line.

The source of power was a turbine-driven 1,500 k.w. alternator with considerable overload capacity. As load, a combination of water rheostat and specially constructed high potential reactive coil were used, which permitted me to experiment with power factors below 40 per cent.

The primary object of the investigation was to determine the behavior of different types of switches, as enclosed oil switches, open tank oil switches, constrained air switches and open air switches, with special reference to the question whether and what electrostatic disturbances were caused in a circuit of high capacity by rupturing it under heavy inductive load. For this purpose, the circuit was, under load, disconnected from the generating system while shunted by spark gaps, and also by the oscillograph, which recorded the variations of potential in the circuit photographically.

From the constants of the line and the load, the frequency of oscillation was calculated and this calculated frequency was found to check very closely with the frequency of oscillation recorded by the oscillograph, 240 cycles and 140 cycles respectively, with two different loads. Even the attenuation of the oscillation in the oscillograph record agreed well with the resistance of the circuits. It is interesting to note here the low frequency of the circuit oscillation. There may be electrostatic disturbance extending over a short space only, as a few layers of a transformer, and therefore of very high frequency, and also correspondingly small power, but the frequency of oscillation of the total system may be so low and near in magnitude to the normal machine frequency that it becomes a very difficult problem to guard against it.

When breaking the circuit with an oil switch, an oscillation was observed starting with an amplitude of about three-quarters of the line potential, and decreasing gradually to nothing in a number of half waves, therefore harmless to the circuit. With the constrained air switch, that is, a switch breaking the circuit at 40,000 volts in the interior of an enclosing tube, the same harmless oscillation appeared, but traces of it were already observable before the final break of the machine current. When, however, this air switch failed to open, and held an arc, the oscillograph recorded an entirely different phenomenon. Instead of the smooth sinusoidal potential wave of the circuit, it recorded the double-peaked wave characteristic of the electric arc, and this potential wave was interspersed with a number of oscillations starting with peaks as high as 115,000 volts, or over twice the normal potential.

Attempts to open the circuit with an open air switch, consisting of two metal rods 5 feet in length, separated by 10 inches at the lower end and flaring away from each other to a distance of 6 feet at the upper end, always failed at 40,000 volts and heavily inductive load, and the arc held. It flared up and stretched out to a length of some 35 feet, and wrapped itself around a pole and climbed up, reaching a line insulator on top of the pole, thereby short-circuiting the system. The short-circuit resulted in discharges and short-circuits of all the spark gaps on the system, due to the excessive rise of voltage incident to a short-circuiting arc, and a brilliant display of fireworks. The brilliancy of the arc was such that a fair photograph of it was taken at noon against a cloudless summer sky.

Especially interesting were the results observed when connecting the generator to the line while open at the receiving end. At

40,000 volts, any spark gap which I considered safe for the line short-circuited, and the oscillograph connected across the line only recorded one or two peaks of voltage reaching as high as 125,000 volts. By lowering the voltage to 30,000, I obtained an oscillograph record showing the starting oscillation superimposed upon the normal wave of the line potential. But while from the line constants a frequency of over 300 cycles is calculated for the oscillation of the line, the photographic record gave a frequency of oscillation between 85 and 90 cycles, that is, quite near the normal line frequency. This frequency explains the unusual viciousness of the starting oscillation. It also shows, however, that the oscillation produced in the line by connecting it to the generating system was not limited to the line only, but extended back into the generating system through step-up transformers into the low potential generator. A rough approximation of the frequency to be expected from the line capacity and the total inductance of line, step-up transformers and generator, fairly agrees with the observed frequency. Oscillations, therefore, may extend over the whole system through transformers and into generators, and an oscillation produced by a disturbance in one line or cable may reach any other line or cable connected to the same generating system, even when fed by separate step-up transformers. This explains the repeatedly observed fact that a breakdown in one circuit or cable causes successive breakdowns or short-circuits in other cables, etc., connected to the same generating system, by the oscillation reaching back to the generator bus-bars and into the generator.

The conclusions which I derive herefrom are that the danger of breakdowns by high potential oscillations is far greater than frequently assumed, and that the most dangerous oscillations are not the very localized oscillations of very high frequency, but oscillations of relatively low frequency extending over the whole or a large part of the system, and due to changes of the circuit conditions, as short-circuits, etc., since they are so low in frequency and so near to the machine frequency that no reactive coil can guard against them without being so large as seriously to impede the normal generator current, and that to protect against these oscillations is probably the most serious problem to be met with in the establishment, construction and operation of high potential systems.

MR. PHILIPPO TORCHIO:—I would like to ask Mr. Thomas if in a 6,600-volt three-phase 25-cycle underground system, as operated in this city, an equipment of spark arresters and static interrupters would be considered necessary or proper.

MR. THOMAS:—That is largely a question of the particular design of the apparatus that is to be protected. On 6,300 volts, with transformers, the concentration of potential, such as the static-interrupter is intended to prevent, would not be a serious matter, because there is margin enough allowed in the design of the apparatus. In the case of a high potential generator, however, which has a great number of turns of wire, and in which it is impracticable to obtain a large amount of insulation, it is entirely possible that if trouble has been experenced in any case, a static interrupter would help very much. A static interrupter (I repeat for the benefit of those who have not noticed this point), has no direct protective power against the grounds; it simply prevents the concentration of potential on a few turns of a coil, and hence is no especial help in cables. The lightning arrester gives protection against grounds. On the 6,300-volt circuits, we probably would need some protection against grounding at the end of cables, possibly at some other point. But unless the generator require protection, I do not see that the static-interrupter would be of any value. The static-interrupter is of special use on high voltages—for example, those of 20,000, 30,000, or 40,000 volts.

MR. TORCHIO:—There is another question which I would like to ask. In a 6,600-volt system, the question of protecting the apparatus itself against electrostatic disturbances is of secondary importance, as the apparatus is designed with a large factor of safety even for very high voltages of an oscillatory nature. In an underground cable system, however, insulation conditions may be poor at several points, as at joints, etc. Now, if a ground develops on one leg of a feeder and at the same time there happens to be a weak spot on another leg of another feeder connected to the same bus-bars, the doubling of potential on this weak spot will break down the insulation and start a short-circuit through ground. Now, if the center of the " Y " connection of the generator were permanently grounded, the grounding of any one leg of the system would cause immediately a short-circuit, against which the cable is well protected by the automatic circuit breakers at the station, but the strain of double potential would be removed from the system. I would like to have Mr. Thomas's opinion on this subject.

MR. THOMAS:—I feel about the question of neutral grounding, that on very high voltages it is probably the best method of operation. Of course, this would depend somewhat upon circumstances. On a system in a large city which has a comparatively low voltage, the desirability of grounding the neutral would depend on the conditions. Certain strains are made less by the grounding of the neutral point. Certain other strains are made greater. There are certain advantages, and it should be determined by the circumstances in any particular case, or perhaps by actual experience, which is the better method of operation. I think this cannot be determined off-hand.

As to resonance, there may be two kinds of resonance; static resonance, that is, resonance in which the exciting alternating force, the force which is necessary for producing resonance, is of a temporary nature, such as some secondary disturbance, like a lightning discharge or breakdown of some kind, which has a limited amount of power and a limited duration; and second, resonance in which the exciting force is the generator. In the first case, a discharge gap to ground may very well be a sufficient protection, because as soon as the voltage rises, this gap will discharge. This will relieve the potential and even if it builds up once or twice more by resonance, the spark gap will discharge again. When the generator supplies the exciting e.m.f., however, there is very much power behind it, and the resonance condition will continue indefinitely; so that a spark gap which will prevent a rise of potential must be able to carry current continuously. Of course such a gap is pretty nearly out of the question; this case would be equivalent to a short-circuit.

PRESIDENT STEINMETZ:—Gentlemen, before adjournment I desire to announce that the next meeting will be held on Feb. 28. The subject will be "Electrochemistry and Electro-Metallurgy." Very interesting papers are promised by Dr. Sheldon, Mr. Bradley, Dr. Keith, Mr. Hering, Mr. Jacobs and others.

The meeting then adjourned.

[COMMUNICATED AFTER ADJOURNMENT BY MR. B. A. BEHREND.]

Mr. Thomas's paper is an extremely instructive and timely summary of some of the phenomena that have obtained prominence in recent years with the growth and development of high potential apparatus. I wish to illustrate some points made by Mr. Thomas by two diagrams which show very clearly the immense strain which has to be sustained by a cable, a transformer or a synchronous or induction motor armature in the moment at which it is put on to the high potential mains. The mathematical analysis from which these curves have been obtained, though somewhat complex, is identical with the theory of the linear movement of heat as given in Fourier's classical work on the "Analytical Theory of Heat." Lord Kelvin in 1855 applied Fourier's analysis to the case of a telegraphic cable in his masterly papers on the "Electric Telegraph" to which I wish to refer, as these researches have a distinct bearing on the phenomena presented by high potential discharges. If we connect 1,000 volts direct current to 10 incandescent lamps in series, by suddenly closing a switch, very often the lamps near the terminals break down, because in the first instant there is a greater potential across them than across the lamps near the middle between the two terminals. This occurs only in the first instant, as after a very short time the potentials across the lamps become equal.

Let us imagine a long cable, one end of which is suddenly raised to the potential 1,000 volts, then at successive intervals of time the potential distribution will be represented by the curves numbered 1, 2, 3, 4, 5, 6, 7, 8, 16 and 256 in Fig. 1.

The general partial differential equation from the integral of which the curves in Fig, 1 are derived is Fourier's well-known fundamental equation.

$$\frac{d^2 v}{dx^2} = C R \frac{d v}{d t} \qquad (1)$$

C being capacity per unit length and R resistance per unit length, the solution of this equation for a cable of length l is expressed by

$$v = V\,(1 - x/l)\left\{1 - \Sigma A_i \sin\left(\pi \frac{i\,x}{l}\right)\varepsilon^{-\frac{i^2 \pi^2 t}{R C l^2}}\right\} \qquad (2)$$

In order to satisfy the equation (1) $\Sigma A_i \sin[\pi\,(i\,x/l)]$ must be equal to the final value of v, i. e., $(1 - x/)\,l\,V$, by which condition the Fourier series, and hence the problem, becomes determinate. Now Fourier and Lord Kelvin have shown that this integral may be transformed into the well-known probability integral which is found evaluated in treatises on the theory of probability. Thus (2) becomes, for an infinitely, or very long cable,

$$v = V\left\{1 - \frac{2}{\sqrt{\pi}} \int_0^z \varepsilon^{-z^2}\, dz\right\} \qquad (3)$$

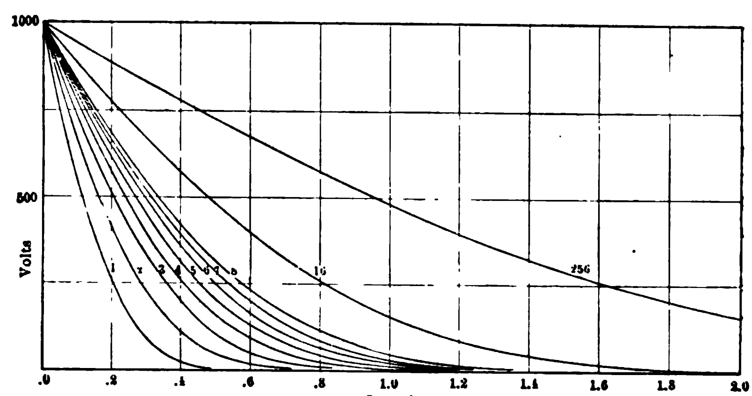


FIG. 1.—Distribution of Potential in a Cable at Different Times and at Different Points.

in which equation z is equal to $\dfrac{x\sqrt{C R}}{2\sqrt{t}}$. It follows directly from the limits of the integral (3) that if t is taken proportional to the square of x, the integral remains constant. Hence, curve 16 being plotted from the table, the curves of the distribution of potential at different times may be found by inserting the times for which we wish to calculate the integral into $\dfrac{x\sqrt{C\,R}}{2\sqrt{t}}$ and changing x so that the fraction remains constant. Thus we obtain the curves in Fig. 1. Lord Kelvin in his paper on " Fourier's Law of Diffusion " plotted similar curves, but he did not plot them for successive time intervals as I have done, probably because this is more wearisome.

It is also easy to transform the Fourier integral (2) into an integral which permits of evaluation by means of a table, but I must reserve this for another occasion. This would then give the conditions for a cable of length l.

The strain which the insulation has to sustain is expressed by

$$S = -K \frac{\partial v}{\partial x} \tag{4}$$

hence the differentiation of the curves of Fig. 1 must give the strain in the cable at different times and at different points. I have carefully worked out these curves for my own satisfaction with the help of the table of the values of the probability integral, and plotted them in Fig. 2. The ordinates of these curves

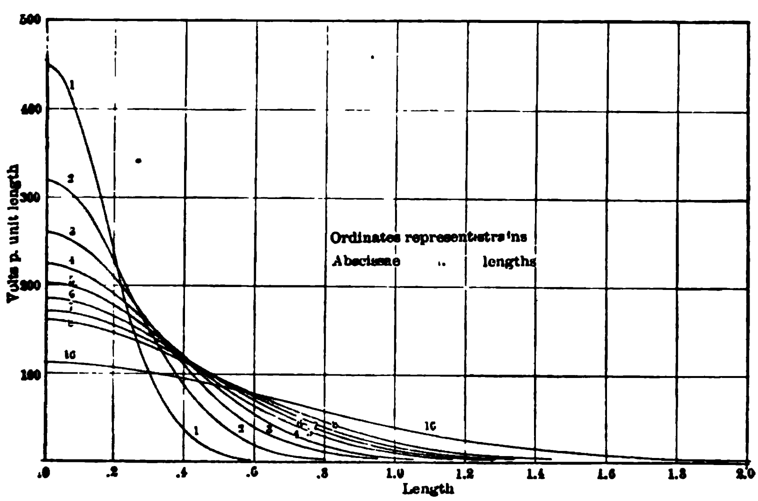


FIG. 2.—Diagram Illustrating Insulation Strains in a Cable at Different Times and at Different Points.

represent directly the strain in the insulation at different times and at different points, and it will be seen at a glance how severely the insulation near the terminal is strained at the moment of putting it in connection with the line.

A mechanical analogy will help us to understand the diagram Fig. 2. Assume the cable to be similar to a rubber hose which is suddenly put in connection with water under pressure, then the hose will stretch, *i. e.*, it will enlarge its diameter in proportion to the ordinates of the curves marked 1, 2, 3, etc., *i. e.*, it will assume at successive moments the shapes represented by these curves, and it is plain that, unless the rubber is very strong, the hose will burst at one end the moment it is put in connection with the water under pressure. Our equations neglect the self-induction and are therefore only approximate, but as they permit a very clear insight into the effect of time on the distribution of potential, no attempt has been made to be more rigorous. In our analogy with the hose we should have to assume the water to be without mass, but having considerable friction along the walls of the hose.

If the transformer is put with one terminal on to the line at the moment of maximum e.m.f., these curves show approximately the conditions prevailing in the transformer as the speed with which the electric wave penetrates is large in comparison with the frequency.

CINCINNATI, August, 1902.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, Feb. 28, 1902.

The 162d meeting of the INSTITUTE was held this evening, President Steinmetz calling the meeting to order.

SECRETARY POPE:—Mr. President, at the meeting of the Executive Committee and Board of Directors this afternoon, the following associates were elected:

Name.	Address.	Endorsed by
AYRES, ALBERT DOANE,	Salesman, Westinghouse, E., & Mfg. Co.: residence, 3808 Grand Boulevard, Chicago, Ill.	C. F. Scott. Arthur Hartwell. W. K. Dunlap.
BURTON, CHARLES GILLETTE,	Salesman, Westinghouse E. & Mfg. Co.; residence, 6328 Greenwood Ave., Chicago, Ill.	C. F. Scott. Arthur Hartwell. N. W. Storer.
CHESTER, M. E.,	Telephone Engineer, Western Electric Co., 463 West St.; residence, 296 Manhattan Ave., New York City.	G. F. Atwood. O. A. Bell. G. A. Hamilton.
CHUBBUCK, LEONARD BURROWS,	Checker in draughting room, Westinghouse E. & Mfg. Co.; residence, (Homewood) 535 Clawson St., Pittsburg, Pa.	C. E. Skinner. H. P. Davis. T. R. Rosebrugh.
COOPER, WILLIAM,	General Superintendent, Bullock Electric Mfg. Co., Cincinnati, Ohio.	R. T. E. Lozier. B. A. Behrend. L. E. Bogen.
COWEN, JULIAN BETTY,	Manager of Export Department, General Incandescent Arc Light Co., 572 First Ave.; residence, 204 W. 119th St., New York City.	Samuel Insull. M. J. Insull. H. P. Ball.
DRYER, ERWIN,	Salesman and Engineer, Westinghouse E. & Mfg. Co.; residence, 171 La Salle St., Chicago, Ill.	C. F. Scott. Arthur Hartwell. N. W. Storer.
ELEY, JOSIAH NORFLEET,	Electrician and Operating Engineer, Georgia Electric Light Co., 198 S. Prior St., Atlanta, Ga.	C. N. Black. W. E. Moore. J. P. Edwards.

Ferris, Robert Murray, Jr., Engineering Department, The N. Y. & N. J. Telephone Co., 81 Willoughby St., Brooklyn, N. Y.; residence, 239 West 103d St., New York City.	J. C. Reilly. J. J. Carty. B. Gherardi, Jr.
Fuller, Edwin Ernest, Representative Engineer for Scotland for The British Thomson, Houston Co.; residence, Abbottsford, St. Andrews St., Ayr, N. B., England.	W. J. Clark. A. Churchill. H. S. Meyer.
Gaylord, Truman Penfield, Engineer, Westinghouse Mfg. Co.; residence, 610 Dearborn Ave., Chicago, Ill.	C. F. Scott. Arthur Hartwell. N. W. Storer.
Gibson, John Jameson, Salesman Westinghouse E. & Mfg. Co.; residence, 171 La Salle St., Chicago, Ill.	C. F. Scott. Calvert Townley. F. A. Pickernell.
Green, Charles Maxwell, Engineer on Brush Arc Dynamos, General Electric Co.; residence, 85 N. Common St., Lynn, Mass.	E. Thomson. C. P. Steinmetz. P. G. Gossler.
Kintner, Charles Jacob, Solicitor of Patents and Expert, 45 Broadway, residence, 36 E. 29th St., New York City.	R. W. Pope. C. W. Price. T. C. Martin.
Kintner, Samuel Montgomery, Professor of Electrical Engineering, Western University of Pa.; residence, 1916 Perrysville Ave., Allegheny, Pa.	C. F. Scott. R. A. Fessenden. H. W. Fisher
Lloyd, Edward William, Assistant Superintendent of Construction, Chicago Edison Co., 139 Adams St., Chicago.	L. A. Ferguson. James Lyman. W. G. Carlton.
Miller, George E., Assistant to Fourth Vice-President, Westinghouse E. & M. Co.; residence, 4911 Centre Ave., Pittsburg, Pa.	R. W. Pope. H. B. Shaw. C. F. Scott.
Morrill, Edward Francis, Engineering Department, The New York and New Jersey Telephone Co., 81 Willoughby St.; residence, 18 Willoughby Ave., Brooklyn, N. Y.	B. Gherardi, Jr. F. H. Dassori. Samuel Sheldon.
Mulligan, Walter Lyon, Assistant Manager, United Electric Light Co., Box 812 Springfield, Mass.	Joseph Sachs. R. W. Pope. G. W. Blodgett.
Lowson, David, Electrical Inspector, Department of Electricity, 1721 Park Row Building; residence, 35 W. 132d St., New York City.	A. A. Nimis. Joseph Sachs. R. W. Pope
Marbury, Louis C., Electrical Engineer, General Electric Co., Schenectady. N. Y.	C. P. Steinmetz. W. R. Whitney. A. H. Armstrong.
ter Meer, Henry Charles, Tester in Meter Department, Brooklyn Edison Co.; residence, 990 Hudson St., Hoboken, N. J.	F. B. Crocker. M. I. Pupin. G. F. Sever.

NICHOLS, LOUIS CHARLES, Electrical Engineer, The Converse Transformer Co.; residence, 602 Shady Ave., Pittsburg, Pa.	H. B. Smith. V. G. Converse. A. L. Rohrer.
PRICE, NORMAN I., Sibley College, Cornell University; residence, 209 Huestis St., Ithaca, N. Y.	G. L. Hoxie. H. J. Ryan. E. L. Nichols.
REMSCHEL, CESAR WILHELM AUGUST G. P. O., San Francisco, Cal.	C. O. Poole. F. E. Smith. C. W. Waller.
RUFFER, CHARLES SHUMWAY, Electrician, The Telluride Power Co., Telluride; residence, Vance Junction, Col.	H. B. Shaw. P. N. Nunn. W.K.Freudenberger
SAWYER, WILLITS HERBERT, Engineer, Railway Engineering Department, General Electric Co.; residence, 4 Gillespie St., Schenectady, N. Y.	C. P. Steinmetz. W. B. Potter. W. I. Slichter.
SHARP, CLAYTON HALSEY, Test Officer, Lamp Testing Bureau, 14 Jay St., New York City; residence, 722 Highland Ave., Newark, N. J.	W. S. Howell. A. E. Kennelly. C. W. Rice.
SLOAN, JAMES RICHARD, Electrical Engineer, The Pullman Co., P. R. R. Depot, Jersey City, N. J.; residence, 607 West 61st Place, Chicago, Ill.	W. M. Stine. W. L. Bliss. A. W. Berresford.
THOMAS, ALFRED CLARENCE, Engineer, The New York and New Jersey Telephone Co., 81 Willoughby St.; residence, 131 DeKalb Ave., Brooklyn, N. Y.	J. C. Reilly. J. J. Carty. B. Gherardi, Jr.
WAGONER, PHILIP DAKIN, Commercial Department, General Electric Co., Box 728, Schenectady, N. Y.	C. P. Steinmetz. W. C. Woodward. C. D. Haskins.
WILKINSON, JAMES, Chief Engineer Birmingham Railway, Light and Power Co.; residence, 1212 North 17th St., Birmingham, Ala.	G. H. Harris. F. E. Kinsman. R. W. Pope.
WOODFIELD, SYDNEY, Assistant Engineer, Electrical Power Distribution Co., York House, Norfolk St.; residence, 24 Sinclair Gardens, Kensington, London, England.	C. W. G. Little. R. W. Pope. F. E. Kinsman.

Total, 33.

The following associates were transferred to full membership:

HOWARD S. WILSON, Superintendent, Puebla Electric Light Co., Puebla, Mex.

CHRISTOPHER M. GODDARD, Secretary, Underwriters' National Electric Association, Boston, Mass.

BYRON T. BURT, Superintendent, Chattanooga Electric Light and Power Co., Chattanooga, Tenn.

LEWIS A. HOWLAND, Engineering Department, Canadian General Electric Co., Montreal, P. Q.

A paper presented at the 162nd Meeting of the American Institute of Electrical Engineers at New York. February 28th, 1902.

THE ELECTROCHEMICAL INDUSTRIES.

BY SAMUEL SHELDON.

Introduction.—In this paper an attempt is made to give a general view of the present condition of the electrochemical industries. The subject of storage and primary batteries is so large and is so clearly differentiated from the other electrochemical industries that it is not touched upon. Neither is the subject of electrotyping considered. The carrying on of the other industries requires over 200,000 horse-power. Of this about 90 per cent. is obtained from water power. The cost of electrical power, obtained from water power, varies much in different parts of the world. Swan gives the limits per horse-power year as $5 and $50. At Niagara the price to large consumers is about $17. This power is delivered in Buffalo for about $30.

ELECTRO-DEPOSITION OF METALS.

Electro-Plating.—The methods of plating employed in establishments in the vicinity of New York do not differ to any extent from the methods well-known in the art. The average practice may be described as follows:

Gold.—There are three solutions in common use to give the three colors of deposit known as "California gold," "green gold," and "red gold." The salts to form the solutions are prepared by dissolving, in nitro-hydrochloric acid, the following alloys: For California gold, an alloy of 22 parts gold and 2 parts silver; for green gold, an alloy of 16 parts gold and 8 parts silver; and for red gold, an alloy of 16 parts gold and 8 parts copper. Upon evaporation the chlorides of these metals remain. They are dissolved in a solution of potassium cyanide to form the plating solution. Double cyanides are thus formed. A freshly prepared solution contains a pennyweight of gold to the gallon. The anodes are of pure gold. The articles to be gilded form the cathodes. The rate of solution of the anodes is not as great as the rate of deposition on the cathode. Therefore the solution has to be enriched by frequent addition of the salts. The current density is adjusted by varying the depth of submergence of the anode, the baths being supplied with five volts at constant potential. The correctness of the current density which is being employed is determined by the eye and the experience of the attendant. There is no circulation of the electrolyte.

Silver.—The solution consists of a double cyanide of potassium and silver, the concentration being two ounces of silver per gallon of solution. The anodes are of pure silver. Owing to the tendency of silver to deposit in arborescent crystals, the articles which are being plated are moved backward and forward in the bath in a plane parallel with the anode surface. The path of movement is about two inches and the time required to traverse it about three seconds. The proper current density rests with the judgment of the attendant. Too great a density or an impoverished solution is indicated by a violet tinge imparted to the deposit. Silver-plated articles to have a polished finish require burnishing with steel or blood-stone burnishers moistened with a solution of soap and distilled water.

Nickel.—The solution universally employed is one of nickel-ammonium sulphate. The proper concentration results from dissolving eight pounds of the salt in a gallon of water. The solution should be kept neutral by the addition of either ammonia or sulphuric acid. The proper current density is from 0.5 to 1.5 amperes per square decimetre of cathode surface. Nitric acid should not be present in any form in the solution.

Brass.—Much house or builders hardware consists of brass-plated steel or iron. Many solutions are used. The best, perhaps, contains equal quantities of zinc and copper cyanides or carbonates dissolved in ammonium carbonate. The color of the deposit may be varied by changing the relative amounts of the copper and zinc salts.

Critical Current Density.—In the electro-deposition of metals from a salt solution the rate of deposition, which may be used, is limited. If a proper current density at the cathode be employed, an adherent reguline deposit will result. If the current density be increased, a limit is reached, when, if exceeded, the character of the deposit will change, becoming pulverulent and non-adherent. This limit is termed the *critical current density*. As an increase of the permissible current density allows of a smaller plant for the same output and shortens the time that the metal in the solution is idle, a consideration of the factors which determine the value of the critical current density is pertinent. Consider a cubic centimetre of metallic salt solution at rest, and directly in front of a cathode. It contains a certain weight of the metal. This weight is dependent upon the concentration of the solution and can be calculated from its specific gravity. A certain percentage of this metal, dependent on the temperature and concentration of the solution, is dissociated and takes part in the electrolytic conduction. If an attempt be made so to adjust the current flowing through this cubic centimetre, that by Faraday's laws the rate of deposition is such that all the dissociated metal ions must be deposited in one second, then, it is evident, the velocity of movement, or migration of the ions, would be one centimetre per second. Such a rate of deposition of ordinary metals from a stationary solution is impossible. The maximum velocity of migration is rather to be reckoned in thousandths of a centimetre per second. If the deposit is to remain reguline, the ions must not be expected to migrate faster. It is possible, however, to adjust the circuit for any current density. As soon as the rate of deposit exceeds the ability of the metal ions to supply it, hydrogen of the solvent appears to take part in the conduction and a pulverulent deposit results, which contain some hydrogen and is said by some to be a hydride of the metal. The critical current density may be increased by increasing the concentration of the solution, by raising its temperature, or by *circulating the electrolyte toward the cathode*.

Circulation.—Circulation of the electrolyte has three functions. It permits of a higher rate of deposition, as mentioned above; it replenishes the part of the electrolyte next to the cathode which has been deprived of its metal; and it prevents, to a certain extent, the deposit from assuming a nodular or aborescent form. When deposition is taking place at moderately large current densities, accidental differences of concentration occur in the vicinity of the cathode. Places on the cathode which can be reached by current flowing through the more concentrated portions of the electrolyte will receive a heavier deposit than other places. As a result they will protrude slightly from the cathode. These unevennesses are multiplied and magnified as the deposition continues.

Dissociants.—The water of an ordinary electrolyte performs two duties. First, it acts as a solvent, whereby it allows and facilitates the uniform distribution of the dissolved substance throughout the solution, subdivision of the substance being carried to a condition of a molecular fineness. Secondly, it acts as a dissociant whereby some of the molecules of the dissolved substance are split up and dissociated into their component ions. Without dissociation there can be no electrolytic conduction of the current. Besides water the following substances are common solvents and dissociants: liquid ammonia, ethyl alcohol, methyl alcohol, glacial acetic acid, and pyridin. The last-named contains no oxygen, and it has been recently shown by Dr. Kahlenberg that from a solution of lithium chloride in it, pure metallic lithium may be electrolytically deposited.

Copper Refining.—Refined copper constitutes the most valuable product of all the electrochemical industries. The processes of producing the refined copper from its alloys have been well described by Badt in the ninth volume of the INSTITUTE's published TRANSACTIONS. The copper alloy, or blister copper, is cast into slabs which are used as anodes in a bath containing a slightly acidulated solution of copper sulphate. This electrolyte is kept in continuous circulation. Pure copper is deposited from the solution upon pure copper cathodes at a current density of from 15 to 25 amperes per square foot. Copper is simultaneously dissolved at the anode, and the alloyed gold, silver, and other metals drop, as slime, to the bottom of the cell to be parted and recovered later. After deposition the cathodes are melted up, poled, and cast into wire-bars or other suitable forms. The " poling" of copper consists in stirring the molten metal with a pine stick. The stick carbonizes, and, as a result, reduces cuprous oxide which is present in the molten copper. Upon cooling, cuprous oxide gives up its oxygen to metallic impurities which may be present in the copper. As the mechanical and electrical properties of copper are better when impurities exist in the form of oxides rather than as metals, the proper amount of poling is when just sufficient cuprous oxide is left to oxidize the impurities. Overpoled or underpoled copper is brittle and of inferior conductivity.

Parting of Gold and Silver.—This is accomplished by means of electrolysis very satisfactorily in the following manner. The alloy of the two metals constitutes the anode, and is placed in a linen bag. The cathode is a thin sheet of pure silver. The electrolyte is at first a one-tenth per cent. solution of nitric acid, which ultimately becomes a dilute solution of silver nitrate. With a current density of 33 amperes per square foot, silver 999.5 per mil fine is deposited on the cathode in the form of beautiful crystals. These are mechanically scraped off and allowed to drop to the bottom of the cell. Gold, in the form of mud, containing some silver, collects in the anode bags. The silver is removed from it by dissolving in nitric acid, leaving the gold in a very pure condition.

Extraction of Gold.—The process of Siemens and Halske, which is in use in South Africa, consists in dissolving the gold from the crushed ore in a solution of cyanide of potash and then subjecting the solution to electrolysis with iron anodes and thin sheet lead cathodes. The anodes are dissolved. Dr. Keith improves upon this process by adding a small amount of soluble mercury salt to the cyanide solution. It increases the rapidity of solution, and mercury is deposited alongside the gold on amalgamated copper cathode plates. The amalgam is scraped from these plates and the gold and mercury separated by "retorting."

Extraction of Nickel.—By the Hoepfner process the nickel ores are first roasted, crushed, and leached in a mixed solution of cuprous chloride and calcium chloride. By electrolysis with carbon electrodes the copper is removed from the solution. The lead and iron are removed by chemical means. There then remains a solution of nickel chloride. This is electrolyzed, and the nickel deposited upon a nickel cathode.

INORGANIC PRODUCTS.

Alkalies and Bleach.—The power employed in the electrolytic preparation of these substances amounts to more than 50,000 horse-power. There are many different processes employed, some of which are secret. The electrolyte is always common salt, either in water solution or in a fused condition. Upon passage of a current, using a carbon anode, chlorine is developed in the gaseous form at the anode and is led to chambers containing lime with which it forms bleaching powder. Metallic sodium appears at the cathode. If the cathode be mercury, as in the Castner process, a sodium amalgam is formed, which, upon washing with water, yields caustic soda and returns the mercury. If the cathode be iron in a water solution, caustic soda is developed by secondary reaction. In the Acker process the electrolyte is fused salt and the cathode is molten lead.

Sodium.—This is manufactured on a commercial scale at Niagara by the electrolysis of fused caustic soda. The electrolyte is maintained in a fused condition by the current which passes through it. An iron containing-vessel constitutes the cathode, and the anode consists of rods which dip into the electrolyte. The sodium after deposition rises to the top of the electrolyte, and floats upon its surface. As it accumulates it is removed by small iron dippers. The sodium, after its reduction, is used in the manufacture of sodium dioxide. This is done by spreading the metallic sodium on trays, which are placed in tubes, supplied with air and dried over calcium chloride. The sodium peroxide is then used for producing peroxide of hydrogen. For this purpose it is mixed with sulphuric acid, and during the mixing the temperature is maintained near zero by melting ice. This is necessary because of the unstable character of the peroxide of hydrogen.

Aluminium.—This metal is reduced electrically from alumina by the Pittsburg Reduction Co. at Niagara Falls in America, and at Shawinigan Falls, in Canada, and by six other concerns in Europe. The annual product in America is about 3,000 tons. Kershaw estimates the total output for 1901 as 7,500 tons. The double fluoride of aluminium and calcium, in a fused state, is used as a solvent and dissociant. The heat developed by the passage of the electrolyzing current maintains the solvent in a fused state. The electrolyte is contained in large cavities made in carbon slabs. The carbon constitutes the cathode, and groups of large carbon rods, dipping into the fused electroyte, constitute the anodes. The metal is drawn off once a day through taps leading to the bottom of the cavities. As the electrolyte is deprived of its metal its resistance rises. This fact is utilized to give warning to attendants. An incandescent lamp is shunted between the electrodes and, as the resistance of the electrolyte rises, the brilliancy with which the lamp burns increases. The attendant then introduces fresh alumina to the fused electrolyte. The process is thus continuous and uninterrupted.

Sponge Lead.—This is produced from litharge by placing it in contact with a sheet lead cathode in an electrolytic cell having a lead anode and dilute sulphuric acid as the electrolyte. The deposited hydrogen reduces the litharge, leaving a lead sponge of fine quality. This process is employed by the National Battery Co. at Buffalo. The Electric Lead Reduction Co. of Niagara Falls is also producing sponge lead by subjecting galena to electrolysis.

Potassium Chlorate.—This is manufactured in considerable quantities by the National Electrolytic Co. at Niagara Falls by the electrolysis of a solution of potassium chloride. The process is not ideal as compared with many other electrolytic processes and the yield is not as great as could be desired for the electrical energy which is employed. The yield is increased by introducing a small quantity of potassium chromate into the electrolyte, as shown by Muller, and the introduction of a little alumina neutralizes the potassium hydrate as it forms at the cathode. The cathodes, as used at Niagara, are of wire gauze covered with cuprous or cupric oxide. The reduction of the oxides by the liberated hydrogen develops sufficient heat to maintain the temperature of the electrolyte at 50°C. The electrolyzed solution is led into refrigerating tanks, where the chlorate is made to crystallize by lowering its temperature.

Ozone.—This gas is a modified form of oxygen. It is generally stated that a molecule of ozone contains three atoms of oxygen while a molecule of gaseous oxygen contains but two atoms. This, however, is uncertain. Ozone differs from ordinary oxygen in being a much more powerful oxidizer at ordinary temperatures. It very quickly oxidizes organic substances. Ordinary rubber becomes brittle and crumbles after an immersion for a short time in the gas.

There are many forms of apparatus devised for the electrolytic production of ozone. The general principle underlying the construction of all of them is to pass a stream of dry oxygen or air between two conducting surfaces which are close to each other. The conductors are subjected to differences of potential which are rapidly varied in amount over wide limits. The high tensions of electrostatic machines, induction coils, or transformers are used. Disruptive discharges may be employed for producing the rapid change of potential difference. One company is using an alternator which gives 10,000 cycles per second. The issuing gas is said to be ozonized. At best it contains but little above one per cent. of ozone. A molecule of oxygen, consisting of two atoms, each bearing an electric charge, when subjected to the sudden variations in the electrostatic field between the conductors, may in some or many cases be torn apart. The constituent parts may join with other molecules of oxygen to form ozone molecules.

Ozone is used on a commercial scale in yielding organic oxidation products, in sterilizing water for potable purposes, and in bleaching fabrics. Among its proposed uses may be mentioned the decoloration and defecation of syrup in sugar manufacturies, the aging of wines, and the aging of woods for the construction of musical instruments such as violins.

Nitric Acid.—One firm which is interested in electrochemistry, has perfected a method for the electrolytic production of nitric acid, the nitrogen being recovered from the atmosphere. The electrical process very materially reduces the cost of production. The importance of such a process may be very great in the future. Nitrogen is essential in the diet of all the higher forms of animal life. Soils are deprived of their nitrates by the crops which are grown. The supply is replenished to some extent by parasites which grow in nodules on the roots of leguminous plants. These parasites are capable of taking nitrogen from the atmosphere and oxidizing it. And yet fertilizers containing nitrates have to be applied to the soils to maintain their productiveness.

Organic Products.

Several hundred organic substances have been prepared in the laboratory by means of electrolysis. Most of them remain as laboratory preparations, but some have come upon the market, being manufactured on a commercial scale. All these organic products may be arranged in four classes, depending upon the ultimate constitution of the substance yielded as compared with the composition previous to electrolysis. Without considering the actual electrolytic process, the effective process is either one of oxidation, of reduction, of concentration, or of substitution or addition. These processes, like all electrical processes, are especially valuable because of the extreme delicacy of regulation which is possible. The efficiency of the process as regards yield is thereby increased.

Electrolytic methods constitute a valuable addition to the facilities at the disposal of the organic chemist. In carrying on experimental work attention should always be given to the temperature, to the concentration, and to the current density which is being employed.

Iodoform.—This is prepared by the electrolysis of ethyl alcohol in a solution of sodium or potassium iodide. The anode is of platinum and is placed in a solution made of 15 parts of potassium iodide, 100 parts water, and 16 parts of ethyl alcohol. This solution is separated by a porous diaphragm from a strong solution of sodium hydroxide, which contains a nickel cathode. The temperature of the electrolyte is kept at 70°C and a current density of one ampere per square decimetre is employed. After passage of the current for three or four hours, the solution is allowed to cool and iodoform crystallizes out.

Chloroform and Bromoform.—It is claimed that by substituting chlorides or bromides for the iodides in the above process either of these two substances may be prepared.

Camphor.—If turpentine hydrochloride, in a melted condition or in an alcoholic acetic acid solution, be electrolyzed, camphor is obtained. Camphor results from the oxidation of terbene, *i. e.*, oil of turpentine. Artificial camphor is made from turpentine in large quantities by the Ampere Electrochemical Co., but the process is claimed to be in nowise electrical.

Vanilin.—This substance, which is the odoriferous component of vanila, is obtained by the oxidation of eugenol (oil of cloves). It is much used in the manufacture of perfumes. It is produced electrically on a commercial scale in France.

Artificial Rubber.—A process for the electrical production of artificial rubber is being experimented with, and it is said to promise much for the future. No details concerning the method are being given to the public.

Furnace Products.

The electric furnace owes its great utility to the facility with which its temperature can be regulated and especially to the great elevation of temperature which is obtainable. The amount of heat which is produced in a conductor is dependent upon the resistance of the conductor. the strength of the current, and the duration of the current flow. All of these are easily altered in magnitude. The temperature of the conductor is determined by the rate of development of heat and upon the facility which is offered for its escape. The ultimate stationary temperature is attained, when the rate of escape of heat is equal to the rate of its production. With a given rate of heat production the temperature rises as the facility for the escape of heat is lessened. The many available heat insulators make it possible to produce any temperature which can be withstood by the conductors.

Calcium Carbide.—This substance, which is prepared by heating a mixture of coke and lime in an electric furnace, constitutes at present the most valuable electrochemical product with the exception of copper. Furthermore, its production requires more power than any other electrochemical industry. Kershaw estimates that in 1900 the power employed was 85,000 horse-power. The rate of production has been in excess of the rate of consumption and the result has been a decrease in the price of the product.

Its value lies in the fact that, when placed in water, acetylene gas is developed to the extent of about five cubic feet per pound of carbide. When burned in air the acetylene gives a flame of great intrinsic brilliancy and of pleasing color quality. Its richness in carbon tends toward a sooty flame. Swan inclines to the belief that the gas may prove of great value in metallurgy as a reducing and carbon carrying agent.

Calcium carbide is put in the class with explosives and dangerous chemicals. It is therefore subject to high freight rates for transportation and is associated with high insurance rates. Owing to the moisture ever present in the atmosphere, it suffers from freight transportation over long distances. These facts militate somewhat against its adoption as a source of illumination for small towns.

Carborundum.—This substance is carbide of silicon. It is an abradent, harder than emery, and is used for the same purposes as the latter. It is made into wheels, into tools of various forms, and into hones. The process of manufacture consists in heating electrically to a very high temperature, a mixture consisting of 60 per cent. pure sand and 40 per cent. powdered coke. To this mixture is added a small amount of common salt and sufficient sawdust to render the mass porous, so that gases, which are liberated in large quantities, may escape. This mixture is packed around a "core" of coarse granulated coke, the grains having diameters of from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch. An alternating current is sent through the core and produces heat, which does not easily escape through the surrounding mixture. The result is a great temperature elevation and the formation of the carbide, some of it being in the form of very beautiful violet-colored crystals.

Artificial Graphite.—Upon the common introduction of arc lighting it was noticed by many observers that the tips of remnant carbons were transformed into something resembling graphite. The transformation extended only over portions of the tips which had been heated in the lamp to a high temperature. In the manufacture of carborundum it was observed that there was always produced a layer of graphite in the hottest part of the furnace. Upon investigation the conclusion was reached that graphite was not formed by merely heating pure carbon to a high temperature, but that a carbide must be first formed and afterwards be decomposed by the electric furnace heat. Therefore it is necessary to have some metallic salt or oxide mixed with the carbon before heating. In practice a good mixture consists of 97 parts of finely divided amorphous carbon commingled with three parts of iron oxide. This mixture permits of moulding into any desired shape, which is afterwards graphitized. The moulded articles are placed inside of a hollow carbon cylinder of about 20 feet in length and 20 inches in diameter. Current is sent through the cylinder in a longitudinal direction. As the articles become graphitized they acquire a greater conductivity, and the current which flows under a given impressed pressed voltage increases accordingly. In practice the original impressed voltage is about 150 and the amperage about 300. As the graphitization proceeds, the voltage is decreased, although the amperage increases.

Barium Hydrate.—The United Barium Company is manufacturing about 60 tons per day of this substance at Niagara. It is in the form of large crystals of an inch or more length on the edge. The manufacture by the electrical method has reduced the price of the product to one-quarter what it was previously. It is consumed in large quantities in the manufacture of pigments, in the purification of water, and in the recovery of sugar from beet molasses. In the last case a ton of hydrate is consumed in the recovery of a ton of sugar. The hydrate is made from crude barytes, this being the only natural source of barium. One equivalent of barytes is mixed with three of barium sulphate, and the mixture is heated in an electric furnace. SO_2, is driven off in the form of vapor, leaving barium oxide behind. This oxide, upon being placed in water, becomes hydrated. It is then allowed to crystallize.

Barium Cyanide.—This substance is made by the Cyanide Company at Niagara. It is used in the production of the other cyanides. Barium carbide, a substance which is the analogue of calcium carbide, is mixed with coke, and producer gas is passed through the mixture while it is being heated electrically. The carbide has an unsaturated molecule, and the three free bonds of each carbon atom easily take an atom of nitrogen.

Phosphorus.—This is manufactured by the Oldbury Electrochemical Co. The electrical process is practically the same as the chemical process, except as to the method of applying heat. Calcium phosphate, either in the form of bones or of natural rock phosphate, is pulverized, mixed with coke, and placed in an electric furnace. Upon passing current through the mixture, the phosphorus becomes vaporized and is collected under water. The electrical process is cheaper than the older chemical one. This is because of two reasons. The temperature necessary to vaporize the phosphorus is quite high. There is therefore a large loss of heat when it is applied to the outside of the closed retorts containing the phosphate. This loss is not present when the heat is produced electrically inside of the retort. Again the practice of the older process was attended with much breakage of retorts, which is absent in the case of the newer.

Corundum.—The Norton Emery Wheel Co. is manufacturing five tons per day of this artificial emery, which differs from the natural emery in being absolutely pure and of uniform specific gravity. The natural variety lacks these two qualities which are essential in the manufacture of a perfectly satisfactory emery wheel. The process of production consists simply in the heating of bauxite in the electrical furnace until water is driven off and the remaining alumina becomes molten. Upon cooling, this latter assumes a crystalline form.

Iron and Steel.—There are a number of experimental plants in various parts of the world manufacturing steel directly from iron ores by means of the electric furnace. None of them has, however, passed the experimental stage. A number of alloys of iron, which are found useful and valuable in the manufacture of steel, are made in considerable quantities by means of the electric furnace. Among these may be mentioned ferro-chromium, ferro-titanium, and ferro-silicon. The first was used in the manufacture of armor plates intended for the cruiser made in this country for the Russian Government.

Silicides.—A very interesting line of substances has been produced by the Ampere Electrochemical Co., by means of the electric furnace, which it has termed *silicides*. They are the analogues of the carbides. Especially interesting is silicide of barium, which decomposes when placed in water with a development of hydrogen gas.

Miscellaneous.

Electrolytic Condensers.—If two carbon electrodes in a solution of zinc sulphate have impressed upon them a small difference of potential, a current will flow until the counter electromotive force of polarization, resulting from the deposition of zinc on the cathode, is equal to and opposes the impressed e. m. f. Upon removing this latter e. m. f. without opening the circuit, an inverse current will flow until the zinc has been redissolved. Such a combination constitutes an electrolytic condenser, its charge being the quantity of electricity associated with the deposited zinc. Its capacity is this quantity divided by the polarization e. m. f. produced by it. This capacity is very large and increases with the area of the submerged portions of the cathode. Such condensers cannot be utilized with potential differences in excess of the maximum polarization e. m. f. They are also very inefficient owing to leakage currents necessary to compensate for local action. For use with higher voltages cells may be used in series. For the same volt-ampere capacity, electrolytic condensers occupy about the same space as ordinary condensers of paraffined paper and tin-foil. They have all the disadvantages associated with liquids.

The Electrolytic Rectifier.—This device in its latest form, as designed by Pollak, consists of an electrolytic cell containing a slightly acid solution of potassium phosphate as an electrolyte. One electrode is of plain lead and the other is of aluminium, which has been formed by macerating it for some time in a solution of caustic soda. If the pressure on a circuit, in which this cell is connected, does not exceed 200 volts, and the temperature of the electrolyte be under 40°C., then the cell will allow current to pass through it from lead to aluminium, but not in a reverse direction. This action is due to the formation of an insulating skin of aluminium hydrate over the surface of the aluminium when it is functionating as an anode. By means of such a cell one lobe of an alternating current cycle can be extinguished. The life of a formed aluminium plate is about 500 hours. The skin then breaks down and separates from the plate.

Electrolytic Interrupters.—The Wehnelt interrupter consists of an electrolytic cell with dilute sulphuric acid as an electrolyte, with a plain sheet lead cathode and with an anode of platinum wire, exposing a small surface (say $\frac{1}{2}$ cm^2). The Caldwell interrupter consists of a cell, with almost any electrolyte, with both electrodes of carbon, lead, or other suitable material, the cathode with its surrounding electrolyte being separated from the anode and its surrounding electrolyte by an insulating diaphragm containing one or more minute perforations. Upon introducing either of these interrupters into a circuit a series of sudden interruptions of the current will occur. These are due to the evolution of non-conducting gases around the platinum wire in the one case and in the diaphragm perforations in the other case. After interruption the circuit closes again as soon as the gases arise, due to their buoyancy. The frequency of interruption can be easily regulated. It increases with increase of impressed voltage, with decrease of inductance and resistance in the circuit, with decrease of exposed anode surface, and with increase of hydrostatic pressure at the place of interrupting gas development. When properly designed and used in the primary circuits of induction coils, these interrupters produce remarkable results. The suddenness with which the magnetic flux which is linked with the secondary, can be made to disappear is responsible for the high e. m. f. developed. The great amount of energy localized at the point of interruption of the circuit is destructive to the surrounding insulation. Lava is employed with considerable success.

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THE ELECTRIC FURNACE IN INDUSTRIAL CHEMISTRY.

BY CHARLES B. JACOBS.

In its early days the electric furnace labored under the burden of the prophecies of its wonderful possibilities and products, and seems to have been more or less associated in the popular mind with the production of diamonds from amorphous carbon, the formation of gems and precious stones from cheap and plentiful materials, and other somewhat sensational operations which had a tendency to obscure, for a time, the knowledge of its usefulness in the field of industrial chemistry.

Notwithstanding the fact that DeChalmot, the Cowles brothers and others, had been operating the electric furnace for some years in the production of alloys from very refractory ores, it was not until Acheson produced carbide of silicon, Willson obtained carbide of calcium in commercial quantities, and Moissan published his scientific investigations in *Le Four Electrique*, that the value of the electric furnace for the production of substances useful in the arts began to be generally recognized.

Since that time, however, its field of usefulness has been steadily increasing until it is now obtaining recognition as an important factor in industrial chemistry.

Reference to the patent lists of the various countries will show an immense variety of electric furnaces, but they may all be classified under three general types which have been modified in numerous ways to meet the special requirements of the various processes for which they are intended.

The three general types of the electric furnace are:

(1) The reflecting are furnace of the Moissan type, in which

the heat of the arc is projected upon the charge by a reflecting surface.

(2) The direct-heating arc furnace, in which the arc is surrounded by the material treated and imparts its heat directly to the charge.

(3) The incandescent furnace, in which either the charge or the walls of the furnace form a part of the electrical circuit and by the resistance offered to the passage of the current produce the required heating effects.

The direct-heating arc and the incandescent furnace are the types most frequently met with in commercial work.

The electric furnace, of whatever type, is, properly speaking, nothing more than a machine capable of producing a high degree of thermal efficiency, for it is not usual in electric furnace work to depend on the current for any electrolytic action; in fact, the alternating current is more regulable and seems to give better heating effects than direct current. When electrolytic action does come into play, the furnace reverts to the electrolytic cell of the type in which fused substances are electrolyzed, but even here the effects depend solely on thermic conditions. The compounds formed or decomposed by a given expenditure of electrical energy are directly dependent upon and calculable from the heats of formation of the compounds in question, by virtue of the relationship which exists between the voltage, heat of formation of chemical compounds and their electrochemical equivalents.

The true type of electric furnace is purely thermal in its effects and has no concern with electrolytic action.

The quantity of heat which may be liberated per second in an electric furnace varies from a few hundred calories in small laboratory furnaces to many thousand calories in large furnaces of commercial capacity. The intensity of the heat or the temperature which may be obtained in an electric furnace is limited and controlled by various conditions, chief among which are the refractability and heat conductivity, or rather lack of heat conductivity, in the material of which the furnace is constructed.

In furnaces constructed with linings of pure carbon blocks reinforced with some very poor conductor of heat, such as magnesia or chalk blocks, it is possible to obtain a temperature close to 4000 C., but at this temperature the purest carbon begins to vaporize.

The temperature to which the charge in the furnace may be raised is of course dependent upon the weight and specific heat of the material to be treated, and this data being known, the temperature obtainable may be calculated with some degree of exactness, especially when the duration of the heating is short and the charge is enclosed in furnace walls of very low heat conductivity, so that the heat generated is mainly absorbed by the charge.

It is comparatively easy to operate commercially at temperatures ranging from 2500° to 3500° C. and to raise the charge almost immediately to the required temperature. Operating at these high temperatures, which may be constantly maintained until the desired operation is completed, reactions will take place between elements which have apparently no affinity for each other at the temperatures obtainable in ordinary combustion furnaces.

All are more or less familiar with the results obtained by Moissan in his electric furnaces, and Borchers claims to have gone far toward proving that every known oxide may be reduced by carbon in the electric furnace.

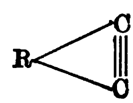
Among some of the most striking of the new chemical compounds of the electric furnace are carbide of silicon, carbide of calcium, and the silicides of the alkaline earth metals.

The carbide of silicon, or SiC, or carborundum, as it is commonly called, was discovered by Acheson about 1893. It is the direct combination of two very similar elements and probably has the structure $Si \equiv\!\equiv C$, the silicon and carbon being linked together by double bonds. It is only a shade less hard than the diamond and has found a ready market as an abrasive and is being manufactured on a large scale by the Carborundum Company at Niagara Falls. Very little of practical value has been discovered regarding its chemical properties, although it will undoubtedly be found to have some striking and very useful chemical properties which sooner or later will find commercial application of value.

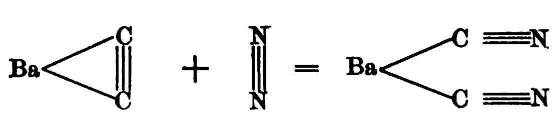
The carbide of calcium, which was first produced commercially by Willson about 1895, we are all familiar with, chiefly from its use in the production of acetylene gas for illuminating purposes. Its importance as a reagent in manufacturing chemistry is, however, becoming recognized, and with the proper investigation of its properties it is only a question of time before its consumption for manufacturing purposes will equal, if not exceed, its present consumption as an illuminant. It is a powerful dehydrating agent and possesses the property of extracting water and even the hydroxyl group from other compounds.

The possibility of using calcium carbide as a means of synthetically producing the valuable constituent of coal tar in a pure state, and the compounds of the benzine series in general, is very inviting; a very pure sample of anthracene, one of the valuable dye products, has been prepared by the Ampere Electrochemical Company, using calcium carbide as the original source of the hydrocarbon.

The carbides of the alkaline earth metals in particular offer a fruitful field for original investigation and synthetic work. The fact that they are unsaturated compounds and are capable of forming further additional products, under the proper conditions, makes them specially attractive.

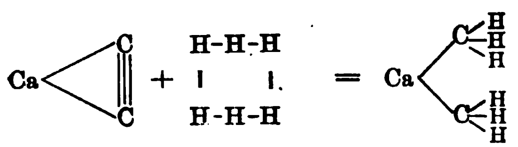
All the evidence seems to point to  (in which R represents the alkaline earth metal), as the structural formula for the alkaline earth carbides, but two of the eight bonds of the two carbons being satisfied by the bivalent alkaline earth metal; the other six are satisfied by the affinities between the two carbons for each other, which is not a very strong combination. If now this compound be heated in the presence of some element having a stronger affinity for carbon than carbon has for itself, the bonds between the carbons will open, and the new and stronger element will attach itself to the carbons of the carbide to form a saturated compound. Nitrogen, for instance, if passed through heated carbide of barium under the proper conditions will, at a certain critical temperature, combine with the carbide, forming a cyanide of the barium.

The structural equation probably best explains what takes place:

 or $Ba(CN)_2$

The Ampere Electrochemical Company has taken advantage of this property of the carbides in the production of the cyanides of sodium and potassium, barium carbide being used as the absorber of nitrogen derived from the atmosphere, and as the carrier of the cyanogen, which is subsequently converted by ordinary chemical means into sodium or potassium salt, the barium being used over again in the production of more barium cyanide.

Hydrogen, if introduced with heated carbides, should combine in the same manner at some critical temperature, forming, for instance, with calcium carbide, what might be called calcium di-methyl.



or $Ca\ (CH_3)_2$

Any of the unsaturated carbides should act in a similar manner.

The silicides of the alkaline earth metals, namely: calcium, barium and strontium, were discovered by the Ampere Electrochemical Company in July, 1899. These compounds which have the formula $Ca\ Si_2$, $Ba\ Si_2$, and $Sr\ Si_2$, respectively, are the silicon analogues of the alkaline earth carbides. The relationship is readily seen when the structural formulæ are compared: Silicon has replaced the carbon of the carbide, R remaining the same in both compounds.

These compounds are formed in the electric furnace under conditions similar to those maintained in the manufacture of alkaline earth carbides, although at a somewhat higher temperature, when the carbonates, oxides, sulphates or phosphates, of the alkaline earth metals are mixed with silica, in which the relative proportions of the alkaline earth metal to the silicon in the mixture is as one to two, and sufficient carbon to effect the reduction is added; or when silicates of the alkaline earth metals in which the molecular relation of the alkaline earth metal to the silicon is as one to two, are mixed with sufficient carbon to combine with the oxygen of the silicates and are heated in the electric furnace. These compounds are white or bluish white substances of metallic appearance, and resemble the silicide of aluminium and metallic silicon somewhat in appearance. They possess a distinctly crystalline structure showing plate-like crystals on fracture. They oxidize slowly in the air at ordinary temperatures, and more rapidly under the influence of heat, yielding silicon dioxide and the oxide of the alkaline earth metal. Like the carbides they decompose with water, but yield instead of acetylene, hydrogen in a pure state, which is evolved without explosion. The following is the reaction between barium silicide and water:

$$Ba\,Si_2 + 6\,H_2O = Ba\,(OH)_2\,2\,Si\,O_2 + 10\,H.$$

Calcium and strontium silicide react in the same manner. The calcium compound decomposes very slowly in cold water, but more rapidly in hot water; barium silicide decomposes rapidly in both hot and cold water, while the strontium compound decomposes more rapidly than calcium, but less so than barium silicide.

All these compounds produce large volumes of hydrogen in a pure state; when chemically pure the following amounts of hydrogen may be obtained from one pound of silicides on treatment with water:

1 lb. calcium silicide,	18.73 cu. ft.	of hydrogen
1 " strontium silicide,	12.36 "	" " "
1 " barium silicide,	9.15 "	" " "

at zero degrees C and 760 M.M.

The silicides decompose rapidly in dilute acids, the barium compound producing silico-methane and free hydrogen according to the following equation:

$$2\,BaSi_2 + 4\,HCL + 6\,H_2O = 2\,Ba\,Cl_2 + 2\,SiH_4 + 4\,H + 2\,SiO_2 + 2\,H\,O.$$

Calcium silicide, strange to say, acts in an entirely different manner when treated with dilute acids and gives rise to the formation of a new chemical compound which has the formula Si_2H_2, the reaction which produces it being as follows:

$$Ca\,Si_2 + 2\,HCL = Ca\,Cl_2 + Si_2H_2$$

This compound is the silicon analogue of acetylene, C_2H_2, and must therefore be called silico-acetylene, since it bears the same relation to silico-methane, $Si\ H_4$, as acetylene bears to methane, CH_4. It is a yellow crystalline solid, and differs in properties from the compound Si_2H_8 which Ogier obtained by sparking silico-methane. The compound of Ogier was unstable and exploded when subjected to a shock. Silico-acetylene is not explosive and is stable at ordinary temperatures. Heated in the air it oxidizes rapidly, giving silicon dioxide and water. When heated in a closed tube, it breaks down into amorphous silicon and free hydrogen. It is insoluble in acids, but when treated with caustic soda and potash solutions it yields hydrogen and a silicate according to the following equation:

$$Si_2\,H_2 + 4\,Na\,OH + 2\,H_2O = 2\,Na_2\,SiO_3 + 10\,H.$$

Strontium silicide is remarkable on treatment with dilute acids, from the fact that it follows both calcium and barium in its behavior, yielding a mixture of free hydrogen, silico-methane and silico-acetylene.

The practical applications of the alkaline earth silicides and of silico-acetylene are many and varied, although the compounds are of almost too recent origin to have touched on more than a few of the most apparent of their uses. Barium silicide seems to be rather the most important of the silicides on account of its great activity and the positive nature of all its properties. Strontium would answer as well for most purposes, but the scarcity of strontium compounds makes it somewhat more expensive and difficult to obtain in commercial quantities.

As a hydrogen producer, barium silicide probably offers the cheapest and most convenient source of pure hydrogen in commercial quantities, it being only necessary to introduce the material into an ordinary acetylene gas generator and add cold water to obtain pure hydrogen.

All the silicides are strong reducing agents for both organic and inorganic compounds.

Barium silicide has been used for the reduction of indigo and seems to offer many advantages over zinc dust and Schutzenburger's reagent. It is only necessary to make the indigo blue into a thin paste with water, and introduce the finely ground silicide. The solution of indigo white thus produced is clean and free from impurities and may be applied directly to the fibre of the cloth or substance to be dyed.

For organic compounds in general, when it is of advantage to make reductions in neutral solutions, barium silicide serves the purpose admirably.

Silico-acetylene may be substituted for barium silicide as a reducing agent when the reductions are carried out in caustic soda or potash solutions.

The silicides of barium and strontium will undoubtedly find many applications as reducing agents in the aniline industry.

One of the large consumers of calcium, as well as barium silicide, will probably be the iron and steel industry. The alkaline earth silicides when melted with iron carrying sulphur and phosphorus have the property of combining with the sulphur and phosphorus, forming sulphides and phosphides of the alkaline earth metal, while the silicon alloys with the iron as silicide of iron. If now the melted mass be blown with air in a steel converter, the sulphides and phosphides of the alkaline earth are oxidized to sulphates and phosphates, while the silicon burns to SiO_2 and these impurities rise to the surface as slag, thus freeing the iron or steel of their sulphur and phosphorus. Tests have been made on irons carrying an excess of sulphur and phosphorus in which the last traces of these troublesome impurities were found to have been removed.

The silicides also offer a good field for original investigation. Tucker and Moody, in a paper published in the *Journal of the Society of Chemical Industry*, October, 1901, on the production of ethylene from inorganic sources, show that when a mixture of barium carbide and barium silicide is melted and the mass treated with water, a gas is produced which contains about 15% by volume of ethylene, and conclude their paper with the statement that it seems possible by the methods they employed to obtain a product which, on treatment with water, simultaneously produces a mixture of ethylene and acetylene. The ethylene is probably produced by the combination of acetylene and hydrogen rendered nascent at the same instant from the carbide and silicide in such close contact as to constitute practically a galvanic couple between the two compounds. This seems to be the most reasonable explanation of the results, since mechanical mixtures of carbide and silicide fail to produce the result.

A practical suggestion offered by the results obtained by Tucker and Moody is that a mixture of acetylene and ethylene might work to very good advantage in gas engines, particularly for automobiles and launches, and the fact that the gas-producing compounds may be stored and conveniently carried in considerable quantity makes the suggestion rather attractive.

The electric furnace has to its credit the commercial production of two of the products of nature which are worthy of mention, namely: the production of graphite from amorphous carbon or coal by Acheson, and the production of corundum from amorphous alumina, such as bauxite or other aluminus compounds, invented by the Ampere Electrochemical Co. and now being operated by the Norton Emery Wheel Co. Both of these processes are in commercial operation at Niagara Falls.

The advantage to the consumer of being able to secure manufactured graphite and corundum in unlimited quantity, and of a higher degree of purity than the natural products, at a competitive price, is of inestimable value commercially, especially since the natural sources of both of these products are, as a rule, isolated from the points of consumption and the natural supply is becoming somewhat limited.

So much for the electric furnace and its new products and their probable value in industrial chemistry. The electric furnace, is, as a rule, only of commercial value in carrying out processes or producing results that cannot be obtained in any other way. The enormous consumption and cost of horse power required for chemical work and the consumption of carbon electrodes are items of serious expense. There are, however, a number of instances in which it is of advantage to introduce the electric furnace to replace the ordinary means of bringing about chemical reactions that take place at high temperatures, since it not only shortens the time required for the reactions and thus increases the yield for a given time, but the reactions in many cases take place much more completely. It also offers the additional advantage of placing the heat at the point required. The substitution of the electric furnace for the ordinary means of bringing about heat reactions is, as a rule, merely a problem of economic engineering.

Working under the Readman process, it has been found advantageous to introduce the electric furnaces in the manufacture of phosphorus; the retorts containing the ordinary mixture of phosphorus-bearing material, silica and carbon are heated from within by an arc, and the phosphorus is distilled off and is condensed under water in the usual manner. The chief feature of the process is economy in breakage of apparatus, due to the external heating by the old method. For the same reason electrical heating has been resorted to in the manufacture of carbon bisulphide. However, the more perfect control of the heat has also been a feature in both of these instances.

Another important use of the electric furnace in industrial chemistry is its application in the treatment of substances which are difficult to reduce, or which yield only a partial reaction even on long continued treatment at temperatures obtainable in ordinary combustion furnaces.

The old method of working barytes or barium sulphate consists in treating it with coal or coke in reverberatory or retort furnaces. By this method from 65% to 75% of the available barium sulphate is converted by reduction into the soluble sulphide of barium, which is then manufactured with other salts of barium.

By a process in operation by the United Barium Company at Niagara Falls, barytes is treated in the electric furnace, whereby from 97% to 99% of the available barium sulphate is converted into soluble form.

The electrical process was invented and developed by the Ampere Electro-chemical Co. Its discovery brought to light a new chemical reaction which takes place beyond the range of temperatures attainable in combustion furnaces.

When a mixture of three molecular equivalents of barium sulphate and one molecular equivalent of barium sulphide are introduced into the electric furnace and the mass brought to a state of fusion, a reaction sets in, according to the following equation:

$$3BaSO_4 + BaS = 4BaO + 4SO_2.$$

The reaction takes place so completely that not more than two or three per cent. of the unconverted sulphate is left in the charge, and taps have frequently been made from the furnace in which the amount of unconverted barium sulphate present was found to be less than one per cent.

The furnace used in the process, is a new form of continuous electric furnace of the direct-heating arc type and is tapped periodically, similarly to an iron blast furnace. The product tapped from the furnace is dissolved in hot water and the insoluble impurities filtered off. The filtrate, which consists of a saturated solution of barium hydrate containing a small amount of barium sulphydrate, is cooled and the hydrate crystallized out as $Ba\,(OH)_2 + 8\,H_2O$. The sulphydrate remaining in the other liquors is separated from the crystals of hydrate and carbonated or converted into some of the acid salts of barium.

Barium hydrate is the chief product of the process, and on account of its extreme purity and the price at which it is produced by the electrical process, has met with a ready sale in fields which have heretofore been closed to it on account of price. The old methods of working barytes do not produce barium hydrate at a price which admits of its large consumption in the arts. The fields into which it is finding its way are the white pigment and dry color trades, the purification of water for industrial purposes, and general manufacturing chemistry. Its largest consumption however lies in the beet sugar industry, for the purpose of recovering the sugar which remains uncrystallized in the molasses. In addition to the domestic consumption for this purpose, some large orders have been booked for foreign consumption. So steadily has the demand for this product increased, that after less than a year's operation it has been found necessary to increase the capacity of the plant to a basis of 60 tons of barium hydrate per day.

A further great advantage of the electric furnace is the facility with which operations may be conducted in the presence of various gases so as to bring their chemical actions into play on other substances at a high temperature, or to make them react together, under the influence of the arc. Some rather striking results have been obtained by the use of hydrogen or gases containing a high percentage of it, such as water gas, upon various substances, particularly silicates, at the temperature of the electric furnace.

If kaolin or china clay be raised to the temperature of the electric furnace, and hydrogen be passed through the highly heated silicates, the hydrogen combines with the silicon to form silicon hydride, according to the following equation:

$$Al\,Si_2O_7 + 8\,H = SiH_4 + 2\,H_2O + Al_2\,SiO_5.$$

The reaction is progressive and if continued the lower silicate first formed will eventually be reduced to aluminium oxide. Metallic aluminium has even been produced by this reaction by continuing the operation with the aluminium oxide, but owing to the high temperature at which the reaction takes place, most of the product is lost by volatilization and the yield of the metal is very small. The lower silicate of aluminium and the oxide formed make very good abrasives with a hardness varying from 8 to 9 in the scale.

The silicide hydrogen issuing from the furnace ignites spontaneously as it comes in contact with the air-producing silicon dioxide and water vapor. This silicon dioxide being the product of the combustion of a gas is in a state of extreme subdivision and makes a polishing agent for silver and fine metal work superior to most of the products in use for that purpose.

Probably no field offers so many important commercial problems for solution as the chemistry of the gaseous elements. The possible synthetic combinations of gases and combinations of the gaseous elements with solids, open an almost limitless field for investigation, including as it does the possibility of the synthetic production of breadstuff, starches, gums, carbo-hydrates and the fertilizers. Undoubtedly the electric furnace and the electrolytic cell will play an important part in the solution of many of these problems. Sir William Crookes pointed out the importance of the atmosphere as a source of nitrogen compounds for the production of fertilizers. Crookes, Lord Rayleigh and others have shown experimentally that chemical combination of the nitrogen and oxygen of the air can be made by means of a disruptive discharge. That their results have remained experimental, is largely due to the fact that their conditions lacked one great essential, namely,—energy. The disruptive discharge has little or no energy. To bring about chemical reactions in anything but trivial amounts, requires a definite amount of energy. It remained for Mr. Charles S. Bradley to take the initiative in grasping the fallacy of the experimental results, and to introduce the energy necessary to bring about the combination of the oxygen and nitrogen of the atmosphere in commercial quantity. The work carried on jointly by Messrs. Bradley and D. R. Lovejoy, first in New York City and for the past year at Niagara Falls, has carried the problem of the fixation of atmospheric nitrogen from the realm of experiment and placed it on a basis of commercial development.

Mention of the process is not out of place in this paper, since in reality the apparatus in which the combination of the nitrogen and oxygen takes place may very properly be classed as an electric furnace of the direct-heating arc type, in which the arc imparts its heat directly to the charge, which in this case is dry air.

The Atmospheric Products Co., with which Messrs. Bradley and Lovejoy are connected in this work, depends for the combination of oxygen and nitrogen upon the proper use of a number of extremely high-tension arcs brought into intimate contact with carefully dried air. In addition to the high tension of the arc, sufficient current is carried to furnish the necessary energy for raising the molecules of nitrogen and oxygen to their ignition or combining point.

The results so far obtained have demonstrated on a practical scale great economy in the manufacture of nitric acid and the nitrates, also nitrous acid and the nitrates, which makes possible the cheap production of all the commercial products which can be chemically derived from these compounds.

Of the value of the electric furnace in purely scientific investigations little need be said. As some one has already pointed out, in the formation of the metallic carbides and their subsequent decomposition, the electric furnace has offered a very plausible explanation of the occurrence of our natural gas, petroleums and bitumens, while the formation of graphite and corundum has thrown still further light on some of the phenomena and products of the various geological ages.

A paper presented at the 162nd Meeting of the American Institute of Electrical Engineers at New York, February 28th, 1902.

ELECTROLYTIC CONDUCTION WITHOUT ELECTRODES.

BY CARL HERING.

Although considerable is known concerning the theory of electrochemical action, there are still many points about which there is not yet indisputable, positive knowledge. About Faraday's law, which is one of the chief foundation stones of all electrochemical actions, there is fortunately no doubt, provided this law is correctly stated, which is not always the case; but about some other fundamental laws which are also important, though less so than Faraday's, our knowledge is not yet of a positive kind. Certain questions, for instance, arise from the fact that *two* electrodes have always been required in every electrochemical action, and all we know concerning certain numerical values, like the e. m. f., for instance, is the algebraic sum of those at the two electrodes, as distinguished from the actual values at each. Electrolysis with only *one* electrode has never yet been possible, and will probably always remain impossible, for if electrolytic conduction is characteristically different from conduction in solids, then in every circuit in which a current flows from one electrode to one electrolyte, there must of necessity alway be a second point at which the electrolytic conduction changes back into metallic conduction. Or, in other words, such a thing as a gradual change in imperceptibly small steps from one to the other must always remain impossible.

Other questions in the theories of electrochemistry arise from the fact that it has always been found necessary to use electrodes in order to pass a continuous current through an electrolyte, and it is therefore claimed by some that electrodes must of necessity form a part of every electric circuit containing an electrolyte, or in other words, that electrolytic conduction without electrodes is impossible, a conclusion with which the writer does not agree. Some even go so far as to define electrolytic conduction by the action at the electrodes, and according to such a definition there would be no electrolytic conduction (as distinguished from metallic conduction) if no electrodes were used. It is, therefore, of no small interest and sometimes it may be of great importance, to know whether electrolytic conduction without electrodes, is possible or not, and to be able to make experiments under such conditions.

It has been suggested to form a circuit entirely of electrolytes separated by porous cups, and choose these electrolytes so that the chemical combination of several of them produces an electromotive force sufficient to send a current through the whole circuit. Whether such a combination is theoretically possible is still questioned; as far as the writer knows, no one has yet succeeded in making just such a circuit, although probably many have tried. It is claimed by some that the direct and counter e.m.f.'s would always add up exactly to zero, just as they do in a closed thermo-electric circuit, the whole of which is at the same temperature, and in which a current would mean perpetual motion. Such an analogy, however, does not seem to be correct, as there is energy set free by many combinations of chemicals. The nearest approach to such an electrodeless circuit seems to be the so-called " liquid element " in which " reversible " electrodes are used at the two ends of a series of electrolytes, that is, electrodes at both of which the chemical change is identical but in a different direction, so that whatever energy is consumed at one, is set free again in exactly the same amount at the other. Copper electrodes in copper sulphate, zinc in zinc sulphate, mercury with calomel in chlorides, etc., are reversible electrodes. Such current-producing cells have been described by Nernst[1] and by Worm Mueller.[2] Evidently the electrodes were used merely to be able to connect the cell to a galvanometer in order to measure the e.m.f. and current, and if the two ends, which always contained the same electrolyte, had been brought together by using a circular trough with porous partitions, and the electrodes removed, a current ought to circulate. For if the

1. *Zeitschrift fuer Physikalische Chemie*, Vol. 4, p. 129, 1889.
2. *Planck: Wiedemann's Annalen*, Vol. 40, p. 561, 1890.

actions at the two electrodes are exactly the same but opposite in direction, the cell ought to give current just as well as if they were removed. Nernst's device, however, was really a concentration cell, the energy of which was not obtained from true chemical combinations, but from the heat of solution or dilution of substances in water.

An unquestionable solution of the problem of conduction without electrodes which has been suggested frequently and has been tried, consists in placing a circular trough around the core of a transformer and inducing an alternating current in it, by making it the closed secondary circuit of the transformer. This will undoubtedly operate, and in fact was tried with success by Behn-Eschenburg for measuring electrolytic resistance.[1]

To show that a current actually flows under these conditions, and to measure it without using electrodes, it has been suggested[2] to make this trough pass around the cores of two separate transformers, so that it is the secondary of one and the primary of the other; by measuring the induced current in the metallic secondary of the second, the current which has passed through the electrolyte could be calculated.

Another method would be to fill a rubber hose with the electrolyte and wind it around the transformer cores, or pass it around an alternating current galvanometer just as though it were a wire. Another method of showing the presence of the current and measuring it without electrodes, is to measure the primary when the electrolytic secondary is closed, and then when it is opened by emptying the tank or inserting a solid insulating diaphragm. Or by replacing the tank with a wire of the same resistance and measuring the current in it, after adjusting it so as to make the primary current the same. These methods are suggested because it has been claimed by some that without electrodes it would be impossible to find out whether the current really flowed or not.

Unfortunately, however, the current produced in the electrolyte by a transformer, is of necessity an alternating one and there are, therefore, no chemical changes in the circuit; for this reason it seems that it cannot be used to settle the question of whether chemical changes, either by substitution or by true decomposi-

1. *Zeitschrift fuer Elektrochemie*, Mar. 2, 1889. *Elec. World and Eng.* April 8, 1899, p. 448. *Electrician*, London, June 2, 1899, p. 202.

2. By Kahlenberg, I believe.

tion, can be produced by electrodeless conduction. Those who believe it cannot, are therefore strengthened in their belief.

It has been thought by some to be an impossibility to devise any apparatus in which a direct current could be produced continuously in an electrolyte without electrodes. As far as the writer can find out, no such apparatus has ever been used, and as it would be of interest, it is safe to assume that if it had been used, descriptions would have been published. Korda describes an alleged unipolar induction apparatus,[1] but it is easily seen by applying the well-known laws of induction, that he has made a mistake, like many other designers of unipolar machines, as the current will not flow as he thinks.

Von Heuser[2] describes an apparatus in which there is unipolar induction. He makes the electrolyte flow in a very rapid stream through a magnetic field. He suggests that it might be used in commercial electrolysis in which the electrodes, which must be used in the ordinary method, are soon destroyed by such products as oxygen and chlorine. His mistake, however, seems to lie in the fact that he believes that the gases will be liberated where a sufficient fall of potential exists, even though there are no electrodes there. It is hardly likely, therefore, that this method of induction could be used for commercial electrolysis.

This brings up the question of the location and nature of the chemical reactions in such a circuit, supposing a current to exist. It would undoubtedly be at the junctions of the different electrolytes; but suppose a gas was evolved by the combination of the two ions which meet there, would gas bubbles rise out of the liquid there? This would be an interesting experiment if it could be devised. The writer has obtained a gas on the surface of a porous partition separating two electrolytes; it was thought at the time to be vapor due to heat, but this would have been condensed immediately in the cold liquid. Unfortunately, the record of this experiment was lost. Another interesting question is whether there would be a similar " skin effect" in electrolytes with high-frequency currents, as there is in solids.

A simple, but slow method of generating an intermittent direct current would be to take the same transformer device above described, but to use an intermittent direct current in the primary, and open-circuit the electrolytic secondary by inserting

1. *Electrician*, and *Elec. Rev.* London, June 30, 1899; *Elec. World and Eng.*, July 22, 1899, p. 135.

2. *Elektrochemische Zeitschrift*, June, 1900.

an insulating diaphragm every time the primary current is broken.

In view of the fact that it has often been claimed to be impossible to induce a continuous current in an electrolyte without electrodes, and in view of the fact that some interesting theoretical questions concerning the electrolytic conduction might be settled by means of such an apparatus, a description of the following, which was devised by the writer some time ago, may be of interest.

The apparatus is in principle a mere unipolar machine in which the current is induced in a column of the electrolyte, instead of in copper bars or disks, as usual. The circuit of this current is

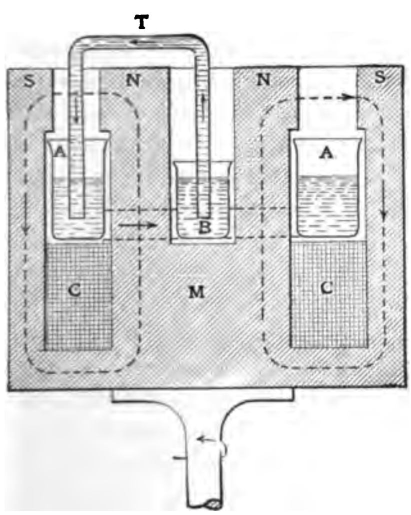


FIG. 1.

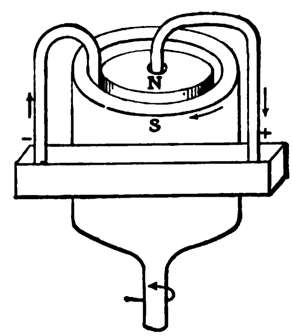


FIG. 2.

then closed through one or more electrolytes, without any electrodes.

Referring to the adjoining Fig. 1, which shows a vertical section, and Fig. 2, a side view of a modification, M is an ironclad electro-magnet with its coil at CC, and the annular air-gap at S N and N S; the paths of the lines of force are shown dotted. It also contains a circular tank, A A, which is connected by means of tubes with the middle tank, B; these are filled with the electrolyte. The whole magnet, with its tank, is revolved. A stationary U-tube, T, also filled with the electrolyte, is inserted as shown, so that one limb passes through and is cut by the magnetic field.

A continuous current will then flow through the liquid circuit; the direction will be as shown if the conditions are those indicated. As the tank revolves with the magnetic field, there will be no induction in the return circuit and the action will be that of a true unipolar machine, so-called. Unfortunately, in all such machines there must always be two sliding contacts, which, in the present case, are where the U-tube enters the tanks. With liquids these may give rise to some inconvenience, but if the ends of the tube are surrounded by porous cups there ought to be no serious trouble due to the pressure produced by the rapidly-moving liquid.

The illustration is only a diagrammatic one, unessential details being omitted for the sake of clearness. In its actual construction the proportions would naturally be quite different.

The top of the stationary tube, T, being visible, may be filled with various electrolytes either separated by porous partitions or contained in mineral gelatine, and the action of the current may be observed therein. If, however, an open trough is desired, the arrangement shown in Fig. 2 might be used; in this the ends of the trough are connected with the liquid circuit in the machine by means of the U-tubes.

The writer has not constructed the apparatus, but merely offers the description of it here to show that it is possible to devise an apparatus in which a continuous direct current can be induced in a circuit consisting entirely of electrolytes.

A simple calculation shows that if the annular field is made about 40 c.m. (16 inches) in diameter, then with a field of 17,000 lines per sq. c.m. there would be induced about 1.8 volt for every 10 c.m. height of the annular field, at a speed of 500 revolutions per minute. As the voltage required to circulate a current in a complete circuit of electrolytes is probably only very small, it would be quite possible to generate it with such an apparatus. It would even be possible to generate sufficient voltage for most decompositions if it were possible to bring about decomposition without electrodes.

The question arises how to detect a current in such an apparatus. One way would be to separate the circuit into parts by porous partitions and place in one of these compartments sulphate of copper and in the two adjacent ones sulphuric acid. Then the blue copper sulphate ought to move into one or the other of these compartments, depending on the direction of the current. Another method is to mix the different electrolytes with mineral gelatine and then place them side by side in a glass trough; the current ought then to produce visible changes at their surfaces of contact.

Such an apparatus would show whether or not such conduction in electrodeless circuits were possible. With a series of electrolytes separated by diaphragms there would then necessarily be changes of composition due to the exchanges of the different ions; there would be what the chemists call mere substitution, such as when precipitates are formed by the mere exchange of atoms, in the mixture of different compounds. Whether or not there can be true decomposition, such as reduction and oxidation (or perduction) which takes place at all electrodes, is quite a different matter, and should therefore not be confused with the other. It is quite an interesting question whether such decomposition would be possible in an electrolytic circuit without electrodes, as it would have an important bearing on the modern theories of electrolysis. It is not apparent how such decomposition could be possible in the light of present theories, and therefore there is no prospect of such a method ever being used commercially for decomposition without electrodes, as was suggested by Heusser, and perhaps others also. For bringing about chemical substitution, as distinguished from true decomposition, such a method might be made useful, but in that case it would probably be simpler to use reversible electrodes, rather than a somewhat cumbersome machine such as the one described above.

In the writer's opinion the above-described apparatus need be used only to settle the first question; that is, whether electrolytic conduction is possible without electrodes, or, in other words, is the action which takes place in the electrolyte independent, or dependent on what takes place at the electrodes. All further questions could then be investigated more readily with the aid of like reversible electrodes, as Nernst and others used.

A paper presented at the 162d Meeting of the American Institute of Electrical Engineers, New York, February 28th, 1902.

LIQUID POTENTIOMETER; DETERMINING ELECTROLYTIC RESISTANCES WITH DIRECT CURRENT INSTRUMENTS.

BY CARL HERING.

In a certain case which recently occurred in the writer's practice, the following problem presented itself. A number of electrolytic tanks were connected electrically in series. But for filling, circulating and emptying, they had to be piped to a common tank. These pipes practically connected in multiple all the liquids in the tanks; hence the tanks, being connected simultaneously in both series and multiple, were all short-circuited. The conditions were such that the usual methods of breaking the continuity of these columns of liquids in the pipes, by means of air bubbles, stop-cocks, successive filling, etc., were by their nature excluded, and the only thing left was to make the resistance of the columns of liquid in the connecting pipes so great that the loss by the leakage current through them, would be negligible. This is always possible, even for a given rate of flow of liquid in the pipes, and given mechanical pressure, because the mechanical resistance to the flow of liquids in pipes decreases more rapidly with an increase of diameter, than the electrical resistance; or in other words, for a given electrical resistance, the flow of liquid with the same head, increases with the diameter of the pipe. In this particular case, however, nothing but lead pipes could be used; and when the fall of potential in the liquid column was made relatively great, the current would naturally leave the high resistance liquid, pass into the low resistance pipe and back again at the other end of it; the object of giving the column of liquid a high resistance would thereby be lost. This was overcome by breaking the electrical continuity of the lead pipe with insulating joints, and the question then arose, at what intervals must these joints be placed so that the drop of voltage in each section would be just below that required to pass from the liquid to the pipe and back again, as the lead pipe, although an excellent conductor compared with the electrolyte, would then act like a pipe of insulating material and confine the current to the electrolyte. In making tests to determine this maximum drop of voltage an apparatus was devised which incidentally led to the interesting fact that the principle of the potentiometer may, with certain precautions, be applied to liquids also, and that such an apparatus may

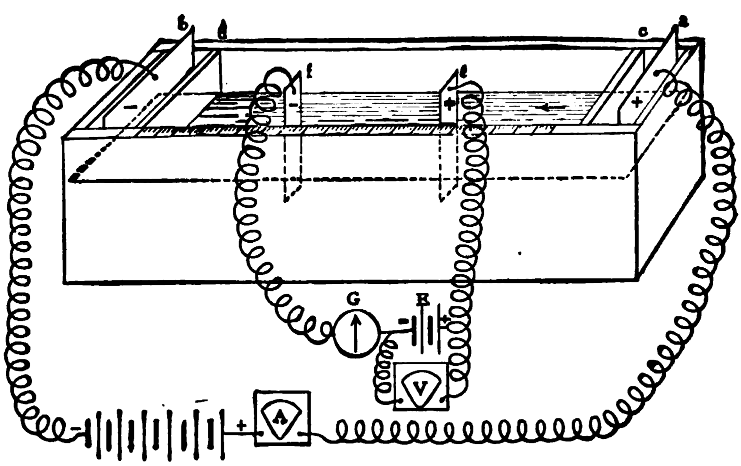


FIG. 1.

be used, among other things, for measuring the resistance of liquids with direct currents, and with only a simple direct current ammeter and voltmeter or galvanoscope, besides a cheap improvised apparatus.

The description of this liquid potentiometer and of the methods of using it, are as follows:

Referring to the adjoining figure, the apparatus consists chiefly of a tank of rectangular cross-section which it made of some insulating material. It should be accurately made, so that the cross-sections of the column of liquid in it are uniform throughout. It should for the same reason be carefully levelled. A scale is attached to one of the upper edges as shown. The tank is filled to any convenient level with the liquid to be tested, and the cross-section of the column of liquid is measured. Any suitable electrodes *a* and *b* are inserted at the two ends, and to prevent the products of decomposition at these electrodes from altering the composition of the liquid under test in the middle of the tank, it is well to separate these electrodes from the rest of the tank by the porous partitions, *c* and *d*, or by placing them in porous cups. The fall of potential at these electrodes and the resistance of the porous cups do not affect the quantities to be measured, and they need not, therefore, be known and may be quite high. A suitable direct current is then passed through the column of liquid by means of these electrodes; it should be constant and must be measured in amperes.

Not considering the ends of the tank, there will then be a regular drop of potential along this column of liquid, like that in a potentiometer wire. If this drop could be measured in volts, between any two points, then the resistance of the column between those points could be determined by Ohm's law, and from this and the known cross-section and distance between the points, the specific resistance of the liquid could easily be calculated.

The difficulty lies in determining this drop of potential without introducing a large and unknown or variable error due to the direct or counter e.m.f., or what is often called polarization, at the electrodes which must be inserted in the liquid in order that a voltmeter may be used to measure this drop in volts. It would evidently be quite improper to use two platinum electrodes connected to a voltmeter, as the shunt current in the voltmeter, even though it is extremely small, would cause very appreciable errors in the form of direct or counter e.m.f.s, at the contact of the platinum and the liquid, as gases would be formed there. Even an electrometer could not be used in this way instead of a voltmeter, as the small charge entering the instrument would produce some chemical decompositions at the electrodes, and thus give rise to an error.

The only correct way is to have absolutely no current flowing in that voltmeter circuit. This is accomplished in a very simple way by inserting a cell, E, of known e.m.f. in this local circuit, taking care, of course, that it is properly connected with respect to its polarity. This need not be a standard cell, but may be any convenient accumulator or primary cell or group of cells whose voltage is measured at the time of making the test; whether it is essential or not that its e.m.f. be great enough to decompose the liquid under test, for reasons which will be better understood later, was not determined; in the writer's tests it was great enough for such decomposition. Any convenient galvanoscope or zero-reading instrument, which may be a sensitive Weston instrument, is then inserted, as shown by G in this circuit, and the two auxiliary electrodes *e* and *f*, are then moved farther apart or nearer together until the current in that local circuit is zero. The resistance of the length of the column of liquid between these two electrodes is then equal in ohms to the quotient of the voltage of that cell by the current in amperes flowing through the tank. Knowing the cross-section of the liquid column, the specific resistance of the liquid is then easily calculated.

The nature of these two auxiliary electrodes for measuring this drop of potential is, however, of very great importance. They must, of course, be identical in material in order that the counter and the direct e.m.f. at their contact with the liquid, balance each other exactly and are thereby eliminated. They must also be chemically inert toward the liquid except perhaps in a case in which the liquid is a salt of a metal, when it might be possible to use electrodes of that metal, as copper in copper sulphate, because there is then no polarization, and the direct and counter e.m.f.'s are equal and opposite; or the so-called "hydrogen electrode" might be used with certain acids; but the writer has not tried these and cannot say whether or not they will answer the purpose. The electrode must furthermore not have the property of combining with the products of the slight decomposition which must take place before the point of zero current has been found, and for this reason platinum will not answer well in the many cases in which oxygen and hydrogen are evolved at these electrodes, because it at once unites in some way with these gases and then becomes useless as an inert electrode. Platinum black electrodes are, of course, still worse for the same reason. Carbon was found to possess this property to some extent also; moreover, it cannot well be had in such sheets that a sharp reading can be taken on the linear scale. It was found that with platinum, for instance, no definite points could be found (when the liquid was sulphuric acid) at which the current would be zero; the position for zero reading would depend upon which direction the current in that local circuit had just before; that is, whether the plates were being moved apart or toward each other; also, on how large that previous current had been.

After trying various metals, it was found that gold was by far the best and was very satisfactory, at least for that large class of electrolytes in which oxygen and hydrogen would be evolved at these electrodes. Two gold coins answered very well when their thickness did not introduce too great an error in the reading of the scale. Gold may possibly not act as well in solutions of chlorides or cyanides; the writer has not tried it in such solutions. It is important, of course, that these electrodes be only slightly immersed in the liquid, so as not appreciably to change the directions of the paths of the current around them.

It was found to be very necessary to approach the zero position from each of the two directions. The simplest way to do this, is to oscillate one of the electrodes very slightly when the zero position has been found approximately; if the needle of the galvanoscope then oscillates on *both* sides of its zero point, the correct position has been found. This method was the one used and gave very satisfactory results. Another method of effecting this oscillation would be to superpose a small alternating current onto the main current in the tank. This might be done by inserting an electro-magnet in the main circuit and vibrating an armature in front of it. Perhaps a current from a dynamo would be sufficiently pulsating; the writer used accumulators as a source. Another method would be to have a small external resistance in circuit with the tank, and to short-circuit it sufficiently rapidly so that the ampere meter will still indicate the mean current.

The deflections just before the zero position was found, seemed to be somewhat of the nature of slow condenser charges and discharges which gradually fell toward zero.

The writer used the apparatus only for obtaining results sufficiently accurate for practical purposes, and therefore is not able to say whether it could be used also as an instrument of precision for research work. For practical work it answers very well, and has the advantage that the ordinary direct current instruments, usually at hand, can be used, the only special apparatus being the tank, which for most liquids can be readily made of wood, coated on the inside with asphalt varnish. The resistances of liquids determined in this way agreed very well with those recorded in tables.

The apparatus was used in the following way to determine the greatest potential at which a current would not pass continuously from an electrolyte into and out of a lead pipe through which the liquid flowed, as described in the introductory remarks. After having determined, as just described, the fall of potential per centimetre of column of liquid in the tank, the test electrodes were replaced by others of lead which were connected through a galvanometer or ammeter (without a battery). When these electrodes were gradually moved away from each other, no current flowed through this ammeter until they were a certain distance apart, and then current suddenly began to flow. Knowing the fall of potential per centimetre, and the distance between the electrodes when current suddenly begins to flow, the desired voltage is readily calculated.

The same apparatus might be used for other purposes also. For instance, to measure the resistance of diaphragms, like porous cups. The resistance of any convenient length of the column is first measured by itself and then with the diaphragm inserted, the increase being that of the diaphragm.

A modified method, which was tried prior to the one described above, proved to be a failure. It consisted in using two electrodes of *different* materals, such as zinc and carbon, for instance, when the liquid was sulphuric acid; these would by themselves produce an e.m.f. when no current was flowing in the tank; this e.m.f. was measured and the current in the tank was then started and increased (or the distance between the electrodes increased for constant current) until the drop of voltage in the column of liquid between these electrodes was just equal to the direct e.m.f. of the electrodes, in which case no current would flow from one to the other. The results, however, were very unsatisfactory and indefinite. The secret of the success of the apparatus lay entirely in the use of the supplementary battery and identical, inert or reversible electrodes.

The theory of the method does not seem to be clear, but as actual and correct results were obtained, there must be some correct explanation. The important points are, that the current in the auxiliary circuit must be zero, so that there can be no chemical decomposition or polarization in this circuit; and that the two electrodes must be alike, so that any possible and unknown e.m.f. that may exist between the electrode and the liquid, is eliminated by the fact that it is always exactly balanced by a second one of equal amount but opposite sign at the other electrode. The electrodes must furthermore be chemically inert in the liquid under test, with perhaps the exceptions above cited. The apparent conflict with theory arises from the fact that it would at first appear that there could be no inverse current in the auxiliary electrodes until the fall of potential between the auxiliary electrodes is great enough not only to overcome the e.m.f. of the battery, but also that for the decomposition of the solution under test. But as such currents were really obtained, it shows that this explanation does not apply. Probably the currents obtained near the zero position are due to the condenser action of the auxiliary battery; in fact, they were more like throws of the needle than steady currents; it was found necessary to watch the deflection of the needle while the electrode was being moved, as the deflection seemed to diminish immediately afterwards. If this is the correct explanation, better results might possibly be obtained by adding a condenser in that auxiliary circuit, parallel to the battery. Or these currents may be what the Germans call "reststroeme," that is, currents which flow before the voltage of decomposition has been reached. Time did not permit making researches to settle this question. This is left to others who may be interested.

A paper presented at the 162d meeting of the American Institute of Electrical Engineers at New York, February 28th, 1902.

POINT OF CUT-OFF IN A BATTERY DISCHARGE.

BY CARL HERING.

In making a test of a battery to determine its output in ampere-hours or watt-hours, the question necessarily arises, when shall the discharge be considered ended. The voltage of all batteries falls as the discharge approaches the end, and if this fall were a sudden and definite one, it could be taken as the proper " point of cut-off " of the discharge; but this is the exception, the rule being that the voltage falls gradually, without any sudden bend in the plotted curve, and it is then difficult to say when the discharge shall be considered to be ended; the point of cut-off is then necessarily an entirely arbitrary one. As the output in both ampere-hours and in watt-hours keeps on increasing, no matter how low the voltage has fallen, much depends on this arbitrary selection of this final voltage, when one is measuring the output of a cell. This is especially important when the output of batteries of different voltages are to be compared with each other, or when comparisons are to be made between the discharges of the same battery at different rates. It is evidently unfair to a lead accumulator, for instance, to always stop its discharge at say 1.8 volts, on closed circuit, when the discharges are made at different rates, or even when one discharge is made at constant current and another at constant external resistance. It is evidently proper to allow a lower final voltage for the higher rates, but the question then arises, what shall the different lowest voltages be at these different rates of discharge.

In some cases the question settles itself. Batteries of the Leclanche or Daniell type, for instance, used on bells or similar work, are of use until their voltage is zero on closed circuit. In practice their drop in voltage will have to be replaced by fresh cells, but as long as they add anything at all to the voltage of the circuit, they are still of use. Zero voltage on closed circuit would, therefore, seem to be the proper point of cut-off in testing such cells.

When used for lighting purposes, the point of cut-off is fixed by the lowest voltage which is still sufficient to run the lamps at their proper candle-power; all above that is of no use, and must be wasted in regulating resistance, unless end-cell regulation is used.

With lead accumulators the point of cut-off of the discharge is generally determined by that fall of voltage below which the plates would be injured. But it is not generally known what this voltage is for different rates of discharge. Nor would it necessarily be the same for different types of lead accumulators.

In still other cases there may be other reasons which determine the lowest voltage to which a discharge should be continued, but there seems to be no general rule which is applicable to all batteries. An approximation to a general rule is to stop the discharge when the voltage has fallen a definite fraction of the original, say 10%. The question then arises, what is to be taken as the original voltage; is it the e.m.f. on open circuit, or the difference of potential on closed circuit; if the latter, then at what time should that reading be taken, as there is always a rapid drop in the first few minutes. A good rule is to take as the original voltage, the difference of potential on closed circuit at which the curve begins to become nearly horizontal. But for a high-resistance battery it would evidently not be fair to assume the same percentage drop for rapid as for slow discharges.

While there may be many cases in practice in which the differences pointed out above are too small to be of great importance, yet there are often cases in which it is very desirable to decide on some definite point of cut-off which is as fair to one as to another battery. This is the case when it is desired to compare with each other, the discharges of the same battery at different rates, or different batteries with each other, or different batteries at different rates.

The first thought was to try to find some curve, such, for instance, as that of an integral or a differential of some of the variables, which has a characteristic point like a zero, a minimum, a maximum, or an inflection point at the proper point of cut-off. A number of trials, however, gave negative results.

Whether or not such a curve exists, the writer is not able to say at present, but if it does, it would probably involve too much calculation to be useful in practice, or the drawing of a new derived curve, which is troublesome.

For the particular case of constant potential, however, a simple solution was found, and as it does not involve drawing a new curve, and admits of a simple graphical solution by a trial method, it seems to be well suited for practical work. This solution is limited, however, to the case in which the battery is to be used on a constant potential circuit, as, for instance, for incandescent lighting, in which case all the voltage above the final is useless, and must be taken care of in the dead resistance of a regulator. The point of cut-off thus found then also gives the

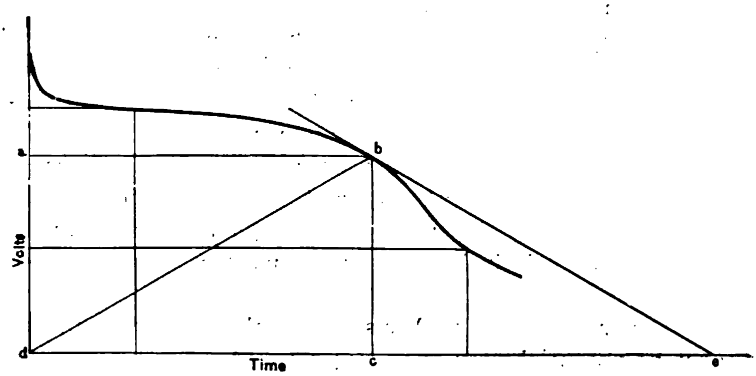


FIG. 1.

proper voltage at which this cell could be used for constant potential circuits; if, for instance, 110-volt lamps are used, then dividing 110 by the voltage thus obtained gives the number of cells required. If end-cell regulation is used, however, this method of finding the proper voltage, does not apply.

Referring to Fig. 1, which is an ordinary constant current discharge curve giving the voltages at successive times, it will be seen that the inscribed rectangles drawn at successive points, continue to increase from the beginning of the discharge up to a maximum and then diminish again. In this case the largest possible inscribed rectangle is *a b c d*. There is, therefore, a maximum of some quantity at this point. It will readily be seen that the area of this rectangle is the product of the volts and the time, or what might be called volt-hours; but as the current is constant, this area is also proportional to the watt-hours. In other words, at that point the maximum output in watt-hours will be obtained; beyond that point the voltage falls so rapidly that the total useful watt-hours begin to diminish, owing to the fact that all the voltage above that is useless. The discharge may therefore be considered ended at that point, and the useful watt-hours, for constant potential circuits, will then be a maximum.

Locating this point by the differential calculus, that is, by making the first differential coefficient equal to zero, led my assistant, Dr. E. F. Roeber, to find the following very simple, graphical solution. It is a method of trials, but a very few trials generally suffice. He found that the angle of the tangent drawn at the point to be found, must be equal to the angle of the line from this point to the origin: from which it follows that the distance *ce* must equal *cd*. The rule therefore is, draw a trial tangent at what is thought to be the right point, then measure *ce* and *cd*, and if they are not equal, the difference will show where to draw a second one, and so on, a very few trials usually sufficing. This method applies only when the discharge is made with constant current, as usual, and not with constant external resistance. The voltage at the point thus found will then be that at which the battery may be used on constant potential circuits.

Although this solution applies strictly only to the specific case of constant potential circuits, it might nevertheless be used also in comparing different batteries with each other, or the same battery at different rates, even when they are not to be used on constant potential circuits, as it gives one a fixed definite point of cut-off, which is determined in the same way for all of them, and may be as fair for one as for the other. It is in any case better than an arbitrarily assumed point.

There is, however, another solution which may be still better; it is to discharge the battery at constant useful power; that is, at constant useful watts instead of at constant current or constant external resistance. This will be found to give a fixed and definite point, which is determined at once during the test, and requires no further calculations; the labor in making the test, however, is increased slightly. The current and the difference of potential at or near the start gives the power in watts; this power is then kept constant by so increasing the current during the discharge that when multiplied by the diminished voltage it gives this constant number of watts. Toward the end of the discharge the voltage will fall rapidly and therefore the current will have to be increased rapidly; this in turn makes the voltage decrease still more rapidly, and a fixed and definite point will, therefore, soon be reached, when the current becomes so great that the battery is no longer able to give that power; this is the point of cut-off, and it is a very definite one, leaving nothing for arbitrary determination.

Such a discharge at constant power seems to be quite a rational one when the battery is to be used for power purposes, as on

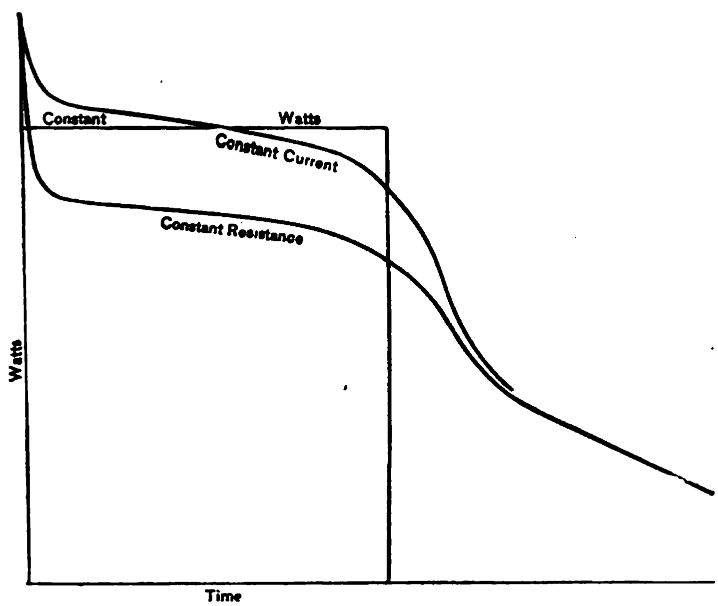


FIG. 2.

automobiles, for instance; but for any good battery the difference between this and a discharge at constant current will not be very great during the greater part of the discharge; the difference becomes great only for a short time near the end.

The test becomes somewhat more troublesome to make, for the reason that the current must be adjusted to correspond to the particular reading of the voltmeter, and the adjustment of the current again changes the voltage, thus requiring a re-reading of the voltmeter and a readjustment of the current; but with a little practice this is easily done. One ought, however, to calculate at the start the current that corresponds to each reading of the voltmeter, so that he does not have to take the time to perform the calculations for each reading, but can simply take it from the table. Such a table is very easily calculated with a slide rule; or, the slide rule may be used instead of the table, as the values can be read off directly.

Fig. 2 shows the curves for each one of these three methods of discharge: at constant external resistance, at constant current, and at constant useful watts. The same primary cell was used in all three, and all other conditions were kept as nearly alike as possible. It will be noticed how difficult it would be to select

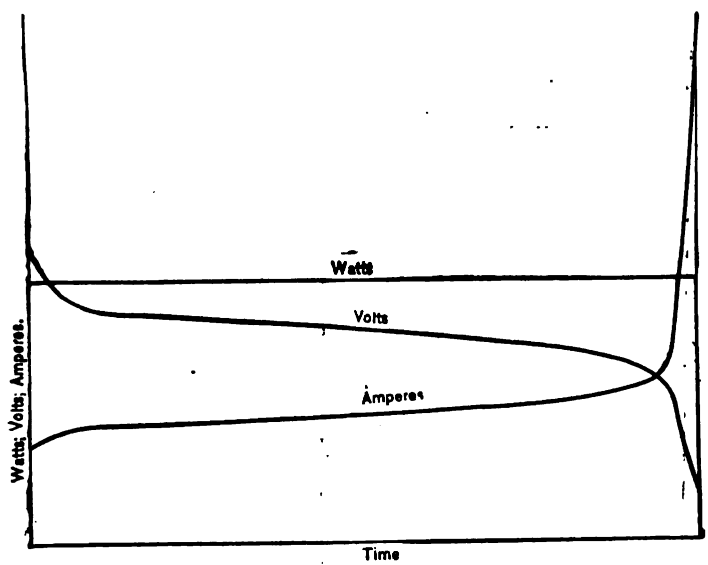


FIG. 3.

any definite point on either of the first two at which the discharge should be stopped, while for the constant power discharge the curve becomes a very definite rectangle, leaving no choice to the experimenter as to when to stop the discharge; it stops itself.

Fig. 3 shows the current curve, the voltage curve and the watt curve for this discharge at constant power. It will be seen how rapidly the current must be increased at the end of the discharge in order to maintain the watts constant as the voltage falls.

In making a constant current discharge of a few small cells, a simple and probably well-known method is to connect them to an ordinary constant potential incandescent lamp circuit in series with as many lamps as are required to give the proper current. The current will then remain practically constant and needs no adjustment as the voltage falls. There is no advantage, however, in using such a lamp circuit for a discharge at constant watts, as one ought to be able to adjust the current by very gradual steps. A carbon rheostat of very low resistances forms the best external resistance to use for that test.

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ELECTROLYTIC RECOVERY OF COPPER FROM LOW-GRADE ORES.

BY N. S. KEITH.

Low-grade cupriferous rocks are those which contain such small amounts of copper per unit (say a ton) of weight that a large number of such units must be treated daily to make a commercial profit.

Where labor, fuel, power, supplies and such requisites are cheap, and the market for the product is near at hand, the percentage of the yield of copper may evidently be less than in cases where expenses are higher, as in regions remote from civilization and the market.

Low-grade ores, may then, also be defined as those which contain from $1\frac{1}{2}\%$ to 5% of copper, with favorable conditions in inverse proportion.

Some low-grade cupriferous rocks may carry enough gold or silver, or both, to make them valuable for treatment for recovery of all the metals when the amount of copper recoverable alone would be unremunerative.

There are two methods, the dry and the wet, by which low-grade cupriferous rocks are treated. In this paper I am to consider but one—the wet. There are varieties of the wet method, but I will confine myself to the one variety in which electrolysis is used to effect the final deposition of the copper obtained in solution during the procedure.

There are many varieties of copper ores which may be treated metallurgically by the wet method, but with many variations the next steps of the operation. These steps are roasting and lixiviation.

While the oxides and carbonates of copper are readily soluble in dilute acids, the cuprous sulphide, or chalcocite is not. Even strong and boiling sulphuric, or hydrochloric acid will not dissolve it. Boiling or hot nitric acid will. But the use of nitric acid is not admissible for other reasons than its expense.

Therefore it is necessary to decompose the chalcocite by expelling its sulphur and oxidizing its copper. This can best be done by roasting. The roasting takes place continuously, as the rock comes from the pulverizers, in a mechanical furnace having a hearth 200 feet long by 10 feet wide, and fired by coal in seven fireplaces arranged along its sides. Rabbles, or rakes, are caused to travel continuously from end to end of the furnace, in their course stirring the powdered rock, exposing continually renewed surfaces to the action of heat and atmospheric oxygen, and moving it to the discharge end. From the discharge end the roasted rock is conveyed to the lixiviation or leaching tanks. The capacity of this furnace is about 125 tons of powdered rock per day of 24 hours.

The reactions which take place in the furnace are these: The carbonates of copper are decomposed, setting free CO_2, and their copper contents oxidized to CuO; the chalcocite is decomposed, the sulphur set free and oxidized, and its copper contents oxidized to CuO; the ferrous carbonates are decomposed and the oxides are further oxidized, which makes them less soluble in dilute acids. The roasting of chalcocite, Cu_2S, does not produce any $CuSO_4$ as in roasting other copper sulphides, for instance, chalcopyrite, containing CuS. There is not sulphur enough in Cu_2S to supply the equivalent of S to form $CuSO_4$. The sulphur of the chalcocite either escapes with the gases of the furnace, or unites as SO_3 with the earthy alkaline constituent of the rock, lime, as calcium sulphate.

There is some calcium carbonate, as calcite, in the rock; say about $\frac{1}{2}$ of 1%. In order to economize in the use of acid it is necessary to mix with the rock as it passes into the furnace some powdered sulphide ores, preferably carrying at least a small percentage of copper; which copper is recovered in the subsequent steps of the process. This is an economic feature; because such ores are cheaply purchased, and serve the double purpose of supplying sulphur to be oxidized and unite with the lime as $CaSO_4$, and a means of obtaining their copper contents. Sulphur may be used in the same manner for the purpose of neutralizing or counteracting the lime. When sulphide, or sulphur, is used in the roasting, much of the copper is sulphated, and as $CuSO_4$ is readily dissolved in water.

The practical result of the roasting is a powdered rock having disseminated therein some $CuSO_4$, some CuO and some FeO and Fe_2O_3; the last of which list is practically insoluble in the acid used.

To extract the copper contents the solvent used is primarily $H_2SO_4 + x\ H_2O$. HCl may be used as a solvent, but there is a difficulty in obtaining anodes which will not seriously deteriorate in the subsequent electrolysis. The percentage of H_2SO_4 is determined by the amount of copper to be dissolved by a definite amount of solvent. The amount of H_2SO_4 may vary from 5% to 15% of the water of the solution.

As will be described further on, after the primary use of the solvent ($H_2SO_4 + x\ H_2O$), another solvent of the copper oxide takes part in the action: namely, $Fe_2\ (SO_4)_3$, ferric sulphate.

From the roasting furnace the rock is conveyed to one of four leaching tanks, filling them in succession. Each tank is cylindrical, 30 feet in diameter and 6 feet high, inside measurements. They each hold 125 to 150 tons of the powdered and roasted rock. The rock is put in hot as it comes from the furnace.

In the bottom of each tank there is a filter bed of coarsely crushed rock, covered with canvas, which is calked tightly around the edges and around the outlets, through which the powder is washed after the extraction of its copper contents.

From the center of the bottom of each tank, under the filter bed, a pipe, with a stop-cock, serves to draw off the solvent to the electrolytic cells.

During the filling of each tank a suitable amount of the solvent is admitted to moisten the rock; and finally, when filled to within about a foot of the top, the whole is flooded by the solvent to the depth of a few inches above the bed of powdered rock.

The solvent begins to run from the bottom of the first filled leaching tank as soon as filled, running through the filter bottom in a stream of perfectly clear, greenish-blue liquid. From time to time, as the liquid on the top is lowered to the surface of the rock, a few inches in depth more of the solvent, drawn from the "stock-solution tank," is run in.

The first solvent run in during the filling of the tank takes up nearly all of the copper, and runs out at the bottom fully saturated with $CuSO_4$. As the fresh additions of solvent pass through the bed of rock they carry decreasing quantities of copper, until all of it has been taken up, and the solvent running out shows little or no more by assay than does the solvent run in.

But meantime tanks Nos. 2, 3 and 4 have been filled, and a like solvent action takes place in them. Then, in order to have a solution of nearly uniform value in copper to electrolyse, the richer liquors from No. 2 are run out simultaneously with the poorer from No. 1. This method is kept up in regular succession with the other tanks.

As soon as the rock in No. 1 has had its copper contents dissolved by the solvent, the outlet is opened and the solution runs into the deposition vats; and as the quantity of copper in the solvent from this tank decreases in amount, the outlet of No. 2 is opened to allow a flow of strong solution to mix with that from No. 1; and so on with Nos. 3 and 4, and then from a new charge in No. 1, and so on, in a continuous cycle of operation. This procedure is for the purpose of supplying the deposition vats with a steady stream of lixiviate having constant percentage of copper.

The tanks are emptied by opening passage-ways through the filter bed and bottom of each tank, and turning a forcible stream of water, pumped for the purpose, against the depleted powder, then called " tailings," thus washing them out; after the manner called " hydraulicking " in some kinds of gold-mining.

The deposition vats are rectangular boxes of wood, protected from the action of the lixiviate, now the electrolyte, by a suitable lining. They are arranged so that the electrolyte flows from No. 1 through Nos. 2, 3 ,4, *et seq*, and finally out of No. 128, depleted of its copper, into a large tank, called the " sump," from whence it is pumped up into the " stock tank " for re-use.

These deposition vats are so set, at differing elevations above the floor of the building, that the electrolyte runs by gravity from one to the next, and so on through the series to the end, through troughs, or spouts, between their ends, with this exception: As the vats are arranged in six rows, and one end of each row is at a greater elevation than the end next to it of the preceding row, it is necessary to raise the electrolyte from the one row to the next at those points. This is done by means of air-lift pumps, which are easily managed.

The electrical connections are as follows: The electrodes in each vat are connected in multiple, and the several vats of electrodes are connected in a series of 128, exactly, so far, as is the case in large storage electric-vats.

But for the purpose of ensuring a retrogressive decrease of density of current at the electrodes of each vat, after the first of the series, the number of electrodes is increased progressively from the first to the last of the series. The amperes of current are the same in each vat of the series; but the current density is less and less in decremental order from the first to the last of the series, to compensate for the decrease of copper in the electrolyte in its course through the vats. Thus the density of current may be 15 to 20 amperes per square foot of cathode surface with a 6% copper solution, and 3 amperes per square foot with a 0.5% solution, provided proper circulation and sufficiently rapid movement of the electrolyte be kept up between the anode and cathode surfaces.

The evolution of free oxygen at the anodes keeps up a continual mixing movement of the electrolyte, in addition to the motion due to the flow through the vats.

During electrolysis there is a counter-electromotive force of 1.6 volts in each vat of the series, due to the difference of energy of combination between the materials on the surfaces of the anodes and cathodes, respectively, and the constituents of the electrolyte. The generator is operated at approximately 240 volts; which gives $240 \div 128 = 1.87$ per cell. The voltage per cell required is $1.87 - 1.60 = 0.27$ volt for resistance of conductors, etc.

The density of current must not exceed in any vat the limit beyond that required for the deposition of reguline copper.

Primarily, both the anodes and cathodes are of sheet-lead. But under the electrolytic action the anodes become coated with PbO_2, and the cathodes with copper. As soon as the copper deposit reaches the thickness of thin cardboard it is stripped off each lead cathode, which is then replaced in its cell, and the two copper sheets thus produced have suitable connections riveted to them, and they are then re-hung as cathodes in some of the vats, where they remain a sufficient length of time to receive a deposit of copper to the thickness needful for the market.

The author has tested anodes of carbon, both such as are used for battery plates, and the Atcheson graphite electrodes. There is much less oxidation and disintegration with the latter; but still too much for economy. There are, also, some other difficulties incident to the use of carbon. Under proper treatment the lead anodes do not sulphate, and the formation of PbO_2 is merely superficial.

A certain proportion of the lead cathode plates are specially used for the purpose, as above, of producing the thin copper cathodes, it being a handier and a cheaper method than providing rolled thin copper sheets for the purpose.

The lixiviate running from the leaching tanks into the deposition vats consists of a solution in water of sulphuric acid, cupric sulphate and ferrous sulphate, expressed symbolically as follows:

$$xH_2SO_4 + 2CuSO_4 + 4FeSO_4.$$

The electrolytic action deposits the copper on the cathodes, perhaps by secondary action, without the evolution of hydrogen, but with the setting free at the anode of oxygen. But some of the oxygen and acid is appropriated by the ferrous sulphate, thus becoming ferric sulphate. When there is enough ferrous sulphate present at the anode, no free oxygen is evolved, but is appropriated by the ferrous sulphate to form basic ferric oxide, which unites with the sulphuric acid to form normal ferric sulphate, as per this equation:

$$x\,H_2SO_4 + 2CuSO_4 + 4FeSO_4 = 2Cu + 2Fe_2(SO_4)_3 + x\,H\,SO_4.$$

Taking the latter half of the above equation for consideration, the two parts of copper are deposited on the cathodes and the solution of ferric sulphate and sulphuric acid runs to the sump tank, from whence it is raised to the stock tank, and from there is used on subsequent lots of powdered and roasted rock in the leaching tanks. While the starting of the plant involved the use of a solution of sulphuric acid for the solvent, all subsequent solvent actions take place in the presence of ferric sulphate and ferrous sulphate as well.

Now, ferric sulphate solutions are energetic solvents of metallic copper, oxides of copper and, to a limited extent, of some sulphides of copper, with reduction from ferric to ferrous solutions and ferric oxide. Take metallic copper and we have this equation:

$$Cu + Fe_2(SO_4)_3 = CuSO_4 + 2FeSO_4.$$

Take cupric oxide:

$$3CuO + Fe_2(SO_4)_3 = 3CuSO_4 + Fe_2O_3.$$

This latter equation shows that ferric oxide (Fe_2O_3) is freed by the solvent action in the leaching tank, and remains there undissolved, thus continually purifying the solution of iron.

The roasting process may sometimes fail completely to oxidize the Cu_2S; if so, then the following equation expresses a further action:

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S.$$

It has been claimed that cupric oxide is dissolved by a solution of ferrous sulphate by double analysis and synthesis, per this equation:

$$CuO + 2FeSO_4 + H_2O = CuSO_4 + (Fe_2O_3 + SO_3) + H_2.$$

The sulphuric acid dissolves some cupric oxide as per this equation:

$$CuO + H_2SO_4 = CuSO_4 + H_2O.$$

It will be seen that all of the reactions result in the production of cupric sulphate in the lixiviate which is to be electrolyzed. There is no deposition of iron on the cathode, even though its sulphate salts are present in the electrolyte in great excess, say near to saturation of the solution.

Unfortunately, the expenses of the operation cannot now be stated, because not yet obtainable. Just as the plant was starting, financial difficulties intervened and caused a stoppage. Enough had been done, however, in an experimental way, to make positive all of the principles of the process; and that, probably, the expenses of mining and metallurgical treatment need not exceed two and one-half dollars per ton. It is probable that work will soon be resumed.

A paper presented at the 162nd Meeting of the American Institute of Electrical Engineers at New York, February 28th, 1902

COLLOIDS.

BY W. R. WHITNEY.

The purpose of this paper is to bring before the INSTITUTE the present condition of investigations in a field which, while it is perhaps primarily of chemical interest, promises to be also of physical, electrochemical and biological interest. It deals with the class of substances known as colloids. The name is due to Graham, who first recognized in gelatinous solutions, such as silicic acid, etc., certain characteristic properties.

It is a well-recognized fact that when two different substances are brought into contact they assume what we call equal and opposite electrostatic charges. This seems to be the case no matter of what the two different substances consist, and is apparently true in case of the solid, liquid or gaseous state. The familiar experiment of rubbing glass or sealing wax with silk, wool or fur is an illustration of this fact, and the action of the various static electric machines depend upon it. The interesting application of the principle in the case of electrostatic differences produced by metals in contact is still a ground for much speculation, and it seems that only in the case of metals which are in contact with solutions, or of different solutions in contact with one another, our knowledge is very far advanced. It should be mentioned, however, that measurements of potential differences between solutions and gases have also been made. We may accept, then, as a postulate, that a physical surface or boundary between dissimilar substances is always the seat of a potential difference.

If a mass of insoluble matter, as quartz, sulphur, turpentine, or even gas bubbles, be suspended in water, the former becomes usually negatively charged, the latter positively. If this material be finely divided by any mechanical process, as by grinding, no reason appears why it should lose its property of being thus charged, and we are immediately brought to consider a condition which probably exists very commonly in nature, though it has not been generally recognized as such. This has been called the colloidal condition, and it is a condition the characteristics of which may be due to these charges, or, more likely, due to the same cause as are these charges. If the particles of quartz or other material were sufficiently minute, it is probable that the repellent force acting between them (they being all of the same sign) would keep them apart and thus also tend to prevent their settling in water. How this might be finally attained as the particles were reduced in size may be seen when it is considered that their weight would diminish in proportion to the reduction of their volume, while the charge would be constant in potential, but increase with the surface exposed, and, for a given weight, a relatively greater surface is being exposed as the particles are further reduced in size. So that the smaller the particles the greater is the influence of the charges.

On the basis of this consideration we ought not to be surprised to find suspensions in water of insoluble matter which never deposit by the action of gravity alone. Finely divided platinum, gold and other metals difficult to oxidize may be brought into suspension in various ways in pure water, and these suspensions are practically permanent. Sulphur, selenium, silicic acid, the insoluble hydrates and sulphides of metals, etc., may be similarly made to assume a stable state of suspension. In short, a careful consideration of the ways in which such suspensions are actually made, forces one to the conclusion that whenever any substance which is by nature insoluble in water is produced in the water in a very fine state of division, a permanent suspension or so-called colloidal solution will result if electrolytes be absent. This fine state of subdivision should exist (as it probably does) in all cases where the insoluble substance is produced chemically *in situ*, for it is produced molecule by molecule. It should also exist where vapors condense in the water, as occurs with subaqueous electric arcs between metal electrodes.

The question naturally arises at this point, why, then, are such suspensions not identical with solutions? This has been the subject of much study and experiment, and it seems now that we are justified in distinguishing between solutions proper and the so-called colloidal solutions (or, more correctly, suspensions) by the following characteristics:

A saturated solution, at any temperature, may be made by bringing the solvent and substance to be dissolved into contact, whereby the process of solution usually commences immediately and proceeds to saturation with a velocity dependent upon the surface of substance exposed. This velocity varies at any instant inversely as the degree of saturation then reached. Suspensions or colloidal solutions, on the other hand, are not made in this way. For example, a mass of sulphur brought into contact with water never produces a colloidal sulphur solution.

Again, in a solution proper, the presence of the dissolved substance produces certain effects called osmotic, which are not produced in the case of suspensions. For example, the solution of any non-volatile substance in water will cause a certain rise in the boiling point of the water and the water will also no longer freeze at 32° F., but at a certain lower temperature. This is not the case with the colloidal solutions, for here the presence of the suspended matter is of little or no influence upon the properties of the water. The tendency of the material of suspensions to diffuse in the liquid is very slight or almost absent, while diffusion of material in ordinary solutions is marked, and its tendency or diffusive force, as measured by the osmotic pressure, is very great.

Another difference must be mentioned, and it is this which is of the most interest from the electrochemical or electrical standpoint. *Suspensions* are usually completely coagulated or precipitated by the presence of small quantities of electrolytes, and this does not occur with *solutions*. A suspension of platinum in exceedingly pure water is a black liquid, transparent in thin sections and perfectly stable. The slightest dissolved impurity in most cases will cause its precipitation, if that impurity be an electrolyte, as a salt. Non-electrolytes, as sugar, are without this effect. The quantitative relations which exist between the amount of platinum thus precipitated or coagulated and the electrolyte precipitating it, are such that a simple chemical reaction seems out of the question. The impurities in ordinary distilled water are usually great enough to precipitate this colloid in a few hours, and therefore the permanent suspension can be made only with the greatest care. It is also true, if not in all, at least in most cases, that the colloidal solution or suspension shows its lack of homegeneity in its action on a ray of light. The ray is scattered by the suspended particles and becomes visible in its path through the liquid, the reflected rays being polarized.

It seems probable that through investigations of the properties of the simple inorganic colloids, as for example pure metal suspensions, sulphides or oxides, we may learn something about the heretofore little understood colloids of nature. The importance of this point is seen when it is recognized that most of the reactions of plant and animal growth and life involve colloidal solutions, such as starch, protein matter, ferments, etc.

We have, then, two kinds of solutions. First, the real solution such as filterable, transparent, homogeneous mixtures of acids, bases, salts, sugar, alcohol, etc., with water, where common, well-recognized laws govern the properties; and second, the colloidal solution or suspension wihch is also filterable and transparent, but does not show many other properties characteristic of the real solution. In this latter class are probably most of the reagents used in the mysterious reactions of living organisms.

In the first class are all the mixtures which conduct the electric current and those of sugar, glycerine, etc., which do not; while in the second class there are no electrical conductors. When, however, a pair of charged electrodes are placed in a pure aqueous suspension, or colloidal solution, the colloidal material very slowly moves from the vicinity of the one electrode to the other—some of the colloids moving with, and some against, the positive current. This fact evidently involves a slight conduction, although I have called these bodies non-conductors because this conduction has never been measured and is doubtless very slight. This motion of the colloidal material is another point of evidence favoring the hypothesis of electrostatic charges on the particles, although the simpler assumption of a polarized form of energy is more exact.

Recent work of Coehn and others makes it seem probable that of any two substances in contact, the one with the higher dielectric constant will be positive toward the other.

The theory of electrolytic dissociation is doubtless more or less familiar to most of you, but it is necessary to consider it a moment in connection with this subject. Experiments show that in most simple aqueous salt solutions, a part of the salt is dissociated. The various properties of those solutions which depend on the relative number of particles or molecules present, such as the boiling point, freezing point, etc., are more pronouncedthan is to be expected from the possible number of whole molecules present. It is also only in the case of these dissociated substances that electrical conductivity through the solution is possible. Moreover, in dilute solutions the degree of this conductivity corresponds to the degree of dissociation as measured by the physical effects referred to. The electromotive force produced by contact of differently concentrated solutions of the same electrolyte may be successfully calculated on the basis of this assumed dissociation and the imagined condition of dissociation seems most probable. The work of Arrhenius, Nernst and others has led to fairly general acceptance of their hypothesis that these dissociated particles are electrostatically charged, and under such an assumption many of the characteristics of these dissociated solutions might be expected. I do not wish to discuss this theory but to call attention to the fact that it is this class of dissociated substances which for some reason exerts the most remarkable influence on our colloids or suspensions. The facts will stand alone without the theory and will remain facts, no matter what is the future history of the theory.

A considerable quantity of a non-electrolyte may usually be added to a suspension or colloidal solution without producing any visible effect, while little more than a trace of an electrolyte is often fatal to the stability of such a suspension. Most, if not all, colloidal solutions are thus coagulable by electrolytes.

It has long been known that the cloudy waters often obtained from stamp mills in mining operations and which carry valuable metal, can be made to settle by the addition of various salts. Lime is usually used for this purpose. It has also been recognized that the silt suspended in a river's water, as our Mississippi, is caused to settle at the deltas, not by reduction in current, but by the presence of salts from the ocean. This silt can be precipitated in a bottle by simply adding a little salt solution. Suspensions or colloidal solutions of metals like silver, gold and platinum are readily precipitated by such small quantities of salts, or of electrolytes in general, that a simple chemical reaction is practically out of the question. Many of the dye-stuffs give solutions which act exactly in the same manner. A number of other organic products of the laboratory have this property, and it is also the property of such suspensions as the insoluble metallic sulphides and oxides; of suspensions made by adding alcoholic solutions of gums or resins to water; or by heating to boiling a dilute solution of egg albumen. These are all cases of electrolytic coagulation or precipitation and seem to be representative types of a large class of processes which occur not only in the chemist's but also in the world's laboratory.

The laws which are being found to exist in the case of these simple suspensions must sooner or later be applied to those cases in Nature where colloidal solutions are undergoing coagulation. It is not absurd to seek their applicability in the case of deposition of starch in the growing plant, of bone and muscle in the maturing animal, etc., for these may well be deposited from colloidal solution by the same actions.

It seems probable from the work already done in this part of the field by various investigators that a small part of the electrolyte which causes the precipitation or coagulation of the recognized suspension is always carried with it into the precipitate. This is usually very small, but a further knowledge of its magnitude in different cases is very much to be desired. Does such an attendant phenomenon occur in the precipitations of nature referred to? The presence of inorganic matter in all of nature's coagulated colloidal material justifies such an assumption of analogy. Nowhere do we find nature's organic products "ash-free," as would be the case if they were the pure colloid.

What function does the electrolyte play in this coagulation? Here speculation is rife. Thus far there seems to be evidence that the coagulation corresponds to the conception of a neutralization of the charges of the suspended particles by oppositely charged parts of the electrolyte.

Many of the facts thus far obtained as the result of experiment can be made to seem consistent on the assumption of already existing hypotheses, and the value of any co-ordination of these facts by these hypotheses must serve as the excuse for their use. We are forced to recognize that the presence of the electrolyte causes the coagulation or precipitation. Bredig assumes that this is brought about by the stress in the dielectric (*i. e.*, the solvent) caused by the presence of the electrostatically charged ions. This would be a natural consequence if the ions are thus charged. Other investigators assume that the electrostatic charges of the particles of the suspension are neutralized by oppositely charged ions of the electrolyte. These charges once neutralized, the forces keeping the particles apart have disappearead and precipitation occurs. This latter seems to accord with many facts, and is a working hypothesis.

Whether a colloid is made up of positively or negatively charged particles may be learned by observing the direction of its motion between electrodes. It has been found that the coagulating power of a certain salt on a given suspension of a negative colloid is practically a function of the concentration of the positive ion only, and, furthermore, that this ion is retained, in some cases at least, by the precipitated colloid, while the negative ion is not. The precipitating power seems practically independent of the nature of the positive ion except that it varies with its valence. There is only one way in which it seems at all possible that this can occur; namely, that the precipitate produced shall contain the hydrate of the metal ion, and the remaining or clarified solution be correspondingly acid. This has been found to be the case in the single colloid which has been thus quantitatively examined.

Furthermore, the coagulating powers of different electrolytes, as, for example, potassium, barium or ferric chloride, where the valence of the metal differs, and where, according to the hypothesis of statically charged oins, the charges differ, are in that numerical relationship which might be expected from the assumption of a neutralization of charges of opposite sign in the coagulation. This calculation was carried out by Whetham practically as follows:

Evidently equal charges should be available from $2n$ triad ions, $3n$ diads and $6n$ monads, where n is a whole number. Probability of contact between colloid and ion should be proportional to the concentration C of the ion or equal to AC, where A is a constant. The probability of two such ions being together is $\overline{AC}^2$ and of "n" ions $\overline{AC}^n$. For equal coagulative power of ions of different valences $\overline{AC_3}^{2n} = \overline{AC_2}^{3n} = \overline{AC_1}^{6n} = B$ (a constant). The concentration of trivalent, bivalent and univalent ions respectively being C_3, C_2, C_1, hence $C_1 : C_2 : C_3 : = I : B^{\frac{1}{6}n} : B^{\frac{1}{3}n} = I : K : K^2$, where K is a constant. That is, from the known coagulating powers of univalent and bivalent ions, that of ions of higher valencies could be calculated. Experimental determinations of relative coagulating power for potassium, barium and aluminium have given the ratio of 1: 32: 1020, approximately, which agrees with the calculation.

This means that a given negative colloid will be equally affected or coagulated by solutions of sodium, potassium and ammonium salts of molecularly equivalent concentration, while barium, calcium, strontium, etc., or bivalent elements, will be much more active coagulants, approximately equal among themselves; and trivalent elements, such as iron, chromium and aluminium, will be most powerful. The ratios of the coagulative powers of these groups, as found by experiment, namely: 1: 30: 1000, also seems to preclude the possibility of simple chemical reactions.

While it is true that most insoluble matter is negatively charged as compared with water, there are some suspensions which are positively charged, and here it is found that the concentration of the negative ion of the electrolyte, instead of the positive, is the factor determining the coagulation. In other words, if chlorine be the ion under consideration, the precipitating powers of all chlorides on this positive colloid will be the same when the concentration of the dissociated chlorine is the same.

If colloidal solutions or suspensions are made up of statically charged particles, the fact that they are precipitated by electrolytes, together with the quantitative relationships of this precipitation and the seeming probability that a part of the electrolyte is rendered insoluble in the process, make the connection of this phenomenon with the electrolytic dissociation theory a most natural one. I personally feel that, conversely, speculation as to possible connections between electrical or electrolytic phenomena in the living plant or animal and the little-understood reactions occurring there is well warranted. Such hypotheses as have been advanced by Professors Loeb and Mathews of Chicago University to explain, among other things, the actions of the nerves and the relationship between nerve phenomena and electrical excitation, certainly lead to renewed attack on old problems and the temporary harm of such a conception even if later shown to be mechanically imperfect, is overbalanced by the numberless additional facts brought to light.

February, 1902

MR. CALVIN W. RICE:—Mr. President, it may be of interest to the INSTITUTE to notice that at the luncheon given in honor of Prince Henry, of the one hundred "Captains of Industry" invited, there were our President, Mr. Steinmetz, five former Presidents of the INSTITUTE, Messrs. Thomson, Bell, Sprague, Weston and Crocker, and six other members, Messrs. Edison, Tesla, Brush, Pupin, Acheson and Morton. Of those who are not at present members, but eminent in electrical interests, there were Mr. George Westinghouse and Mr. Vreeland.

PRESIDENT STEINMETZ:—Gentlemen: the topic of to-night's meeting is Electrochemistry, a branch of electrical engineering which, when this INSTITUTE was founded, and even ten years ago, was hardly existing or in its very beginning, while now a very large part of the country's water-powers are utilized in this branch of the electrical industry.

Many commodities, well-known to us from old times, such as copper, etc., are now produced electrolytically in large quantities, while materials which ten years ago were mere chemical curiosities are now in everyday use, as aluminium, calcium carbide, etc., and substances as carborundum, unknown heretofore have been introduced into the industries and arts by being produced by electrical means.

The electrochemical industry is based upon two features of the electric current—the electrolytic action and the electrothermal action. For electrolysis, electricity can be used only as continuous current, or at least is so used thus far. For electrolytical dissociation of chemical compounds, only very low voltages are required, since the chemical union of atoms is dissolved by very low electric force, a few volts at the most. The result is that the electrolytical industry employs very large currents at very low voltage, and relatively low, even when series connection of very many electrolytic cells is employed.

The second use of the electric current for chemical work is based on the heating effect of the current. Here the electric current has no direct chemical action, and is merely a means of producing heat in the electric furnace.

We can distinguish two types of electric furnaces, the arc furnace, where the heat of the electric arc is utilized, and the incandescent furnace, where the electric current passes through very refractory resistances and thereby produces heat, and both types, while to a certain extent interchangeable, have some different characteristics.

The arc furnace is necessarily the more powerful. The temperature is the highest which has ever been reached by artificial means, a temperature at which chemistry almost ceases to exist. There are very few chemical compounds which still exist at that temperature. Almost all chemical unions have been dissolved there.

In the incandescent furnace any temperature may be reached up to the temperature where the material of the furnace disintegrates or evaporates, boils or melts down.

The electric furnace thereby gives us a very useful means to reach temperatures beyond those which can be reached by combustion; that is, temperatures beyond the maximum temperature of combustion as limited by the temperature of dissociation of the result of combustion; that is, temperatures beyond those where water, vapors and carbonic oxide dissociate in their atoms. At these high temperatures, the electric furnace is the only means of producing the temperature; below, combustion may be utilized.

No matter how efficient an electric furnace is, the heat produced from electricity necessarily must be very much more expensive than the heat produced by combustion, since by combustion virtually all the chemical energy is converted into heat, but by the electric furnace there is converted into heat only the electric energy which in turn is only a very small part of the chemical energy of the coal fired under the boilers of the engine driving the generator. Therefore, the electric furnace can find efficient application only for producing heat beyond the range available by combustion, and furthermore, to a more limited extent, below the range of temperature available by combustion in the case where a very accurate control of temperature is required, or where the ordinary means of heating are unsuitable for the particular purposes, for reasons outside that of efficiency, as deterioration of apparatus, etc.

In the electric furnace continuous current as well as alternating current may be used, since only the heating effect of the current is required. However, alternating currents are practically always used, owing to their greater facility of generation, of transmission and especially of control. So the electric furnace is virtually always an alternating furnace, while for electrolytic work continuous current is used.

Besides these two phenomena, the electrolytic action and the electrothermal action, there is still a further effect of the electric energy, that is, especially at high voltages, the direct disintegrating or combining action of electrostatic stress, as you observe in the Geissler tube, etc., and I believe now efforts are being made to utilize this for electrochemical work.

MR. J. W. LIEB, JR.:—Mr. President, before you call upon the gentlemen who are to present papers this evening, permit me to call to your attention the fact that we have with us as a guest, Mr. Maurice Leblanc, whose name is almost as well-known to the electrical industry in America as it is in Europe. I am sure that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS is pleased to have Mr. Leblanc here, and will extend to him a hearty welcome.

PRESIDENT STEINMETZ:—I have had the pleasure already of greeting personally Mr. Leblanc, and in the name of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS I now cordially welcome Mr. Leblanc, and give him the greeting of our institution. We hope to see him more frequently here.

Discussion.

Dr. Sheldon then presented his paper. He was followed by Mr. Charles B. Jacobs on " The Electric Furnace in Industrial Chemistry." Mr. Carl Hering presented three papers entitled respectively " Electrolytic Conduction without Electrodes," " Liquid Potentiometer—Determining Electrolytic Resistances with Direct Current Instruments," and " Point of Cut-off in a Battery Discharge." Papers were also presented by Dr. N. S. Keith on " Electrolytic Recovery of Copper from Low Grade Ores," and by Mr. W. R. Whitney on "Colloids." [See p. 281-350.]

President Steinmetz:—Gentlemen, we have listened to a series of very interesting papers. Before I call for the discussion, I believe that I voice your sentiments by saying that we shall all be glad to hear a few words from our distinguished guest and visitor, Mr. Leblanc.

M. Maurice Leblanc:—(*Translation.*)—Never so much as this evening have I regretted not knowing English, for I do not know how to thank you for your excellent reception.

This is the first time that I have come to America. The little that I have seen thus far has inspired me with the greatest admiration for your prodigious activity and the greatness of your undertakings, as well as with the desire to become acquainted with your country in the most complete manner.

When I return to France I shall not neglect to communicate my impressions to my colleagues and make them share in the welcome which you so kindly wished to extend to us.

I thank you once again, gentlemen, and tender my best wishes for long prosperity to the Institute.

President Steinmetz:—I now call for the discussion and should like to hear first from Mr. Bradley, who, as we all know, has given a great deal of attention and study to this subject, and has done a good deal in the field of electrochemistry.

Mr. Charles S. Bradley:—Mr. President and Gentlemen: I have been scheduled for a paper on experimentation in electrochemistry. I find very little time to devote to such a subject, but I will state to you in a few words my ideas for the conduct of this line of business, or in fact, any experimental business. My conclusions have been reached after fifteen years of study and twenty years of experience.

I would first call your attention to the theory of evolution. Although mentioned in the early ages, even in ancient Grecian literature, it was left for Darwin, Spencer, Huxley and other eminent men to spread it. It has reached the scientific people and they have applied it in all sorts of ways, but it is not yet intelligently applied in business. Undoubtedly, there are business men who appreciate the full value of it, but really the mass of business men have not yet found out that the theory of evolution applies to all kinds of business, even to their bookkeeping; if they would study they would see it.

My idea is simply the application of the theory of evolution to experimental work. We first require the man as a nucleus. Next we require a little money and a laboratory. Five hundred dollars will determine, by careful application, whether an idea is worth going ahead with or not.

When any invention is worth developing, we should carefully select the man as a nucleus, then the laboratory, and we have, then, the basis of a process. Next, we require a company—a company which may be evolved, not with the enlarged capital stock which most people seem to prefer, but with small capital. Then we require more work; then we require more capital, and so the whole thing evolves, step by step, and we need also very soon a corps of men to conduct the business. We need that much sooner than people have any idea of. No one man has the whole thing in his mind—he cannot have it and that shows the necessity of a company.

A company is a very valuable thing in a great many different ways. It gives steadiness of purpose. It brings all sorts of minds to bear upon the subject. It brings the restraint of one man upon another, and the mistake that most persons make is that they do not employ enough men. They need to employ men, when the latter apparently have nothing to do. We have men in our employ who are not really doing anything useful for the time being. They think they are. That is all right. I want them to go on thinking that they are doing something useful, and before long we will find that some one of them has done a very creditable thing—something that is worth more than all of our capital stock. We have to trust to the average of results, and it is surprising what those results are. In a few years, if not at present, we will be able to show remarkable results. If I were to take you into our confidence and show you our accounts throughout, you would say, what a success you have made since 1897. Whatever has been done was accomplished by applying the theory of evolution, and such intelligence as we could bring to bear on it, or more exactly speaking, making such selection as to produce the best results. It is very much like a tree, putting out its roots in all directions. Some of these roots run against a rock and they stop growing; others go on and draw sustenance for the tree. Of numberless experiments that are tried, out of a hundred perhaps one shows some promise. It is just the same as when the tree puts out its roots; some of the roots die off, others survive.

I hope that some day I can write this out in good shape so that it may be a lesson for the future, because the world needs now to stop and take account of stock. It needs to learn to apply the scientific facts that have been gathered in the past two or three hundred years, or in other words, to apply the knowledge of evolution, selection and survival to the ordinary affairs of life and especially to new work.

We also need the application of ethics. Your Committee on Papers has asked us to give papers here, and it has found that some of us are loath to do so. Why? Because we do not wish to give away our business. We do not wish to tell the whole of any process which we may have. We expect that some one will go to work and become our competitor, which would injure our prospects. Therefore, we try to keep quiet.

Now, this should not be the case. We should not be afraid of anybody. The world should not impose that upon us, and if the theory of evolution was thoroughly studied, and if science was thoroughly studied, and if people would take account of stock, they would not compete. I have tried in every way in our business to avoid competing with any electrochemical industry. If our men come to me and say that they have a process for the production of caustic soda, I say, "No, sir, stop work right where you are; there is no use; there are thousands and thousands of things we can work on without working on caustic soda. There are four or five concerns trying to produce caustic soda now and we do not wish to injure them." So, we apply the knowledge we have gained to something else, and if all would do the same, we would be perfectly willing that you should come to our manufactory and look over every bit of it. If this thing were fully understood, then we might all have complete confidence in each other, and all enjoy the experience of each in his own particular line.

I would like to correct one or two statements in Dr. Sheldon's paper, on the subject of camphor. The production of camphor is one of the processes of our company. He says "But the process is claimed to be in no wise electrical." That is perfectly true. The statement he makes is this: "If turpentine hydrochloride, in a melted condition, or in an alcoholic acetic acid solution be electrolyzed, camphor is obtained." This statement is nothing to us except that it might lead somebody to go into a lot of experimenting that would be useless. The alcoholic solution of any hydrous acetic acid with pinene hydrochloride dissolved in it is a very poor conductor, and almost a non-conductor, and when water is added the specific resistance is more than 1833 ohms; that is, the resistance of a centimetre from one face to the other is 1833 ohms. This shows you that we could not get current enough through it to produce any practical results with any moderate size of apparatus.

The next statement is "Camphor results from the oxidation of terbene, *i. e.*, oil of turpentine." And then he goes on to say, "Artificial camphor is made from turpentine in large quantities by the Ampere Electrochemical Company."

In an experiment which was tried in the laboratory on April 7, 1900, a part of a sample of pinene hydrochloride was melted in a crucible, two electrodes introduced. Various pressures up to 80 volts were tried. The distance was then lessened until the electrodes were short-circuited beneath the surface of the liquid. It seemed to be an insulator, and it did not appear to undergo electrolysis. I think that this disposes of the application of electricity to these things in a commercial way. However, Mr. Jacobs can take up the subject, if we have time later in the evening, and show the reason why these could not produce practical results on account of the chemical formulas.

The camphor is produced by treating turpentine with oxalic acid, which produces the pinene oxalate. This oxalate is then treated with lime or with any other of the alkalies, preferably lime, which produces the oxalate of lime and sets free borneol. This, which is distilled and caught in a condenser, is then treated with an oxidizing agent, which converts it into ordinary camphor, or the camphor of commerce. The camphor that we produce is not the artificial camphor in the sense in which that name is generally used in the market. The market calls hydrochloride of turpentine artificial camphor, but our camphor must be distinguished from this. Ours is synthetic camphor and has exactly the same properties as the camphor of commerce.. We have tried to substitute a great many substances for the oxalic acid but all fail to produce camphor.

I notice that artificial rubber has also been mentioned. This is also thoroughly chemical, nothing in the line of electrical application.

My opinion is that the chances in organic chemistry for the application of electricity will be very small. It is possible that with some of the starches or allied substances, in which there is a possibility of using water solutions, there may be a field for work —what I mean is for commercial results, where you can produce quantities enough to make it pay. Perhaps this statement might be modified, and I might say that where the price of the stuff is extremely high we might be able to produce sufficient quantities to make it pay, but wherever the price is low, this would probably be impracticable.

Referring to Mr. Hering's paper, the unipolar machine has led to more mistakes than almost anything that has ever been thought of. In fact, Prof. Crocker and myself built one once that was made in the most beautiful fashion and we ran it some 2,000 turns. It had a hundred turns of wire and it was supposed to cut the magnetic field and then the wire was carried down through slots. We hoped by going through the slots that we would dodge the magnetic lines. We tried it, and we did not get much current. We could not see that we got any. Finally, after repeated efforts, we connected it directly with a mirror galvanometer of 5,000 ohms, and it not so much as moved the needle. We could wet our fingers and touching the binding posts generate enough current to move the spot off the scale, but this machine would not generate a particle. I do not see where it is possible that Mr. Hering has completed his circuit here, unless it goes through the body of iron of the magnet. There must be a return somewhere, and if there is, he has the electrodes there just as we have in all kinds of electrolytic cells.

MR. CARL HERING:—In replying to Mr. Bradley's criticism, I call attention to the radial channels or tubes, connecting trough A with trough B and shown in dotted lines; there is also an arrow showing the direction of the current in them. These channels are stationary, with respect to the magnetic field, hence they do not cut the lines of force, and no e.m.f. is induced in them. This return circuit of the electrolytic circuit, therefore, consists entirely of electrolytes without any electrodes; the current does not return through the metal of the magnet, as Mr. Bradley supposed, but through insulated tubes passing through the iron.

DR. C. A. DOREMUS:—Mr. President: I fully coincide with what Mr. Bradley has said as regards the evolution of chemical work. Anyone who is familiar with the chemical industries in Germany, France and England, knows exactly why they have evolved into the prodigious establishments which there exist; why it has been found feasible to have a hundred or more trained chemists constantly at work on problems which apparently have no direct influence on the business, but which in later years turn out to be most influential in the particular business in which that company is interested and which mould the policy of others.

In this country we are just beginning to appreciate the value of our raw materials. In the last twenty years our chemical laboratories have been turning out young men more or less according to American methods. It is about time that we should begin to feel their influence on our industries, and with the possibilities which electricity has brought, of being able to put heat where we want it, and current where we want it, and other actions where we want them, and as we have the water powers to generate the electricity, or the oil and the gas and the coal to generate the fire to give us the electricity, there is no reason why we should not be able to bring about wonderful transformations of matter.

No chemist is unfamiliar with the fact that there is required a definite amount of energy in every chemical reaction. He is no true disciple of Faraday if he does not know it. I think that in the next few years we will see in this country a growth which will amaze ourselves as well as other people, and it need not be in the direction of improvements on what has been possible, but, as has already been brilliantly shown in this country, in the development of new industries.

In speaking, not in criticism but in discussion, on some of the papers from a chemical standpoint, I think it is unfortunate to use the word "colloids." It is a misleading term. Prof. Whitney, in his opening remarks, speaks about the use of the word by Graham. Now, the colloids of Graham and the "suspended" particles in solution which Prof. Whitney afterwards alludes to are so entirely different in their physical properties that they ought not, in my mind, to be classed in the same group as "colloids."

If we precipitate silicic acid from a silicate solution by the use of hydrochloric acid, it re-dissolves immediately in the acid and we get a solution which is absolutely transparent, which contains much salt and which may be passed through filter paper, but which will not pass through parchment paper.

When put in a dialyser, the salt will go through faster than silicic acid, but the silicic acid will also go through, and we call this dialysing or dialysis. If we change the water often enough we finally get a solution of silicic acid in the dialyser, which may be concentrated to about 14%. It is absolutely transparent, but will, on proper provocation, become a perfect gelatine. Such silicic acid is one of Graham's colloids.

If, on the other hand, we place a very little gold solution in a bottle of perfectly pure water and add a pinch of phosphorus dissolved in ether, the gold is precipitated in such minute particles that the liquid looks transparent and red; by reflected light it is perfectly yellow. With a lens we can trace the rays of light, which we cannot do with a silicic acid solution, where there are no suspended particles. The solution of gold will continue to settle for months. I had such a solution for over a year in the laboratory. There will be a deposit and that deposit will vary in color according to the fineness of the gold deposited, just as when we pass an electric spark from a Leyden jar through a thread of gold, we can deposit the gold on a piece of glass, gold of all colors, green, red, yellow and violet. Now, the gold "solution" is really a mass of suspended particles not colloidal, because if we place it on a filter, it will run through the filter radially but not axially, the latter collecting the gold particles. It seems to me that we ought to have very clear ideas about these two types of "solutions."

The electric influences or the electrolytic influences are not always the ones that will bring about coagulation. For instance, if we extract from the stomach of the calf a body called chymosin, an infinitesimal quantity of it, placed in warm milk, will solidify the milk so that it will not fall out if the vessel is turned upside down. The casein has become jelly almost in an instant. Chymosin is not an electrolyte. This is a very different thing from putting a little salt into the gold "solution" where the gold is suspended.

When we discuss theoretical matters, the use of words is a matter of very considerable importance. Chemists speak of a dialysed iron solution, which is hydrate of iron in a perfectly soluble transparent form, which is a "hydrosol" condition, but if we convert that into precipitated iron hydrate, it has the "hydrogel" form. We have alumina in just these conditions. We can dialyse aluminium salts and get aluminium hydrate in the hydrosol condition, and it will coagulate into a hydrogel form. We can convert aluminium hydrate in an alkaline solution into the dialysed form, or from an acid solution into the dialysed form. In one case we get a hydrogel form that will unite with coloring matters and in the other it will not. Are these conditions electrical?

Dr. N. S. Keith:—Mr. President: while commending Dr. Sheldon's paper, I desire to supplement it with a few considerations.

The actions and reactions in both battery and electrolytic cells are analogous; and are those of analysis and synthesis. If these be not reciprocal, the counter-electromotive force of polarization is set up in a battery, as in an electrolytic cell, wherein the oxygen and hydrogen of water are dissociated. In a deposition cell containing a suitable cupric sulphate solution, with soluble copper anode and a cathode, already having a coating of copper, unless the current be made too dense, the copper is dissolved from the anode and deposited on the cathode in equal amounts, and there exists no other resistance to the passage of current than those of the electrolyte and conductors.

Right here let me say that we need some distinctive terms with which to designate three kinds of cells in which chemical actions are caused by currents of electricity. One of these may be typified by the cell having platinum electrodes and acidulated water for the electrolyte, in which, practically, the action is only analytical, inasmuch as water is analyzed by dissociation of its oxygen and hydrogen. Another is illustrated by the copper cell I have just mentioned. Still another, but nearly related to the first, is illustrated by the cell in which there is an insoluble anode and an electrolyte from which a metal is deposited on the cathode, while at the anode the acid of that metal's salt is set free, with perhaps a secondary reaction resulting in evolution of free oxygen thereat.

If Faraday's term, " electrolysis " is to be used to define decomposition by means of electricity, then the true electrolytic cell is the first which I have named. If it is to be used, as it has been by many, for all the cells, we need names for the three distinctive types.

As to the proper density of current to keep just below the " critical limit: "—this critical limit is a variable under conditions of kind of metal deposited, character and quantity of the metallic salt in the electrolyte, temperature and circulation of the electrolyte, etc. The more active these conditions are, the greater is the facility with which the ions are presented to the electrodes. It is as essential to success that the anions be presented to the anodes in kind and quantity as that the proper cations be presented to the cathode. Therefore, " circulating the electrolyte towards the cathode " would not have its alleged effect, if such a procedure did not likewise, as it does, cause a similar movement of the liquid toward the anode in the circulatory movement.

But this " critical limit " of density to prevent simultaneous deposition of hydrogen cannot be observed with all metals. In the art of electro-gilding, hydrogen is always evolved with the gold, and the gold is deposited in reguline condition. Tin and lead are deposited in crystalline, arborescent forms; tin with evolution of hydrogen; lead without.

There is no evolution of hydrogen in the parting of gold and silver, referred to by Dr. Sheldon, though the silver is deposited in arborescent, crystalline form. In the electrolytic assay for copper, the current density is so great, especially at the end of the deposition that the copper would be deposited as a black powder, if the free nitric acid present did not act as a depolarizer, absorbing hydrogen, thus forming nitrate of ammonia ($NH_4 NO_3$).

There being at the command of the electrochemist the all-pervading energy, through the agency of means called electrical, what can he not accomplish? The power of analysis and synthesis is with him. He composes, decomposes and recomposes the compounds of the elements to fill economic wants, or necessities, where nature has not supplied them in sufficient quantities at his hand; or, with his magician's wand, he converts otherwise apparently useless materials into substances of greater value to mankind.

We are upon the threshold of this temple of science in which there are glories yet to be seen and understood. There are some barriers to be removed; but the nearer we approach the great hall of the temple, less and less formidable will be the obstructions.

I wish also to say a little about the following statement in Mr. Hering's paper: " Because the mechanical resistance to the flow of liquids in pipes decreases more rapidly with an increase of diameter, than the electrical resistance; or, in other words, for a given electrical resistance, the flow of liquid with the same head, increases with the diameter of the pipe."

This is not exactly understood by me—because, setting aside the friction due to the flow of liquids through pipes, the conductivity of all diameters of columns of liquid for a given length are proportional to the squareof the diameters, as in other conductors, and the flows of the liquids have the same ratio.

As far as I can gather from the paper, the substitution of rubber hose, or tubes, might have been made for the lead pipes, with the elimination of the conductivity of the sections of lead pipe. If it be the case that any given liquid is a conductor only because of the electrolytic actions which take place in it, and that the electrolytic results are a true measure of the current, what more do we need to determine its conductivity or, conversely, its resistance, than to observe the length and cross-section of the electrolyte, and the difference of potential between the anode and cathode, when the surfaces of both electrodes are of like material; as, for example, copper in a cupric sulphate solution wherein analysis and synthesis are equal and opposite, and Ohm's law is directly applicable. In case of electrolytes where there is polarization, then the applied electromotive force minus the counter-electromotive force of the cell divided by C will equal R. But, so far as I can gather from the paper, the practical purpose which was to be served might as well have been satisfied by the direct application of Ohm's law, considering the counter-electromotive force, if any existed, as a simple resistance. The method is ingenious, and I trust it may have practical application, but I think it is subject to sources of error due to the instability in the number of ions presented to the electrodes, arising from movements in the electrolyte and movements of the electrodes. At rest, a higher resistance will be shown than would be the case if the electrodes are kept at constant parallel distances apart with a transverse movement across the tank.

In considering the subject of electrolytic conduction without electrodes, I desire to write a formula or two on the board to show one way that the question whether a flow of current takes place in the case of the arrangement devised by Mr. Hering may be illustrated. Thus:

$$\left\{\begin{array}{cccccc} H_2 & O & H_2 & O & H_2 & O \\ Cu & (SO_4) & Cu & (SO_4) & Cu & (SO_4) \end{array}\right\}$$

$$\left\{\begin{array}{cccccc} (SO_4) & Cu & (SO_4) & Cu & (SO_4) & Cu \\ O & H_2 & O & H_2 & O & H_2 \end{array}\right\}$$

$$\left\{\begin{array}{cccccc} H_2 & O & H_2 & O & H_2 & O \\ Fe & (SO_4) & Fe & (SO_4) & Fe & (SO_4) \end{array}\right\}$$

$$\left\{\begin{array}{cccccc} (SO_4) & Fe & (SO_4) & Fe & (SO_4) & Fe \\ O & H_2 & O & H_2 & O & H_2 \end{array}\right\}$$

$$6\,Fe\,SO_4 + 6\,H_2O + Aq = 2\,Fe_2\,(SO_4)_3 + Fe_2O_3 + H_6 + 3\,H_2O + Aq$$

If we consider these ions as being the liquid in the tube or in a hose of some special form, as suggested, having sulphate of copper solution in water, it might be said that any decomposition that would take place would be counterbalanced by composition, and that it would not show that any action had taken place.

By substituting a solution of ferrous sulphate in water, having the same circuit without any anode, if there be any current induced in such a long tube, and of sufficient electromotive force, (very little electromotive force would be necessary if any current will flow at all), the result will be a combination of the ferrous sulphate with oxygen, which would be set free from the water, producing a result which may be expressed in this way: six of ferrous sulphate, plus six of water, plus an indefinite quantity of water of solution. We have, then, as a result two parts of ferric sulphate, plus ferric oxide, which would be deposited, plus six of hydrogen, which would be set free, plus three of water from the compositions and decompositions, plus the quantity of water which is present as a solvent (see equation above).

Mr. W. R. Whitney:—I would like to answer the remarks of Prof. Doremus. I would be glad to be held responsible, if I could, for the application of the word "colloid" to what we now call "suspension," but I cannot be credited with it. It is a common term in the literature of the subject, and all suspensions which have recently been made are called colloids by the persons who have made them and investigated their properties.

I think that future investigation will show that they are of the same nature and that all materials which we have been calling colloid, such as gelatines, and all that class of substances, are suspensions, pure and simple. We see this more particularly when clay is suspended in water, but the properties are identical, and I cannot be credited with the application of the term. It is just like the word "automobile". It is a word that we would like to get rid of, but the term "automobile" has come, and it has come to stay.

MR. EDWARD P. THOMPSON:—The longest way round is the shortest way home, perhaps, in electrical theories as well as in domestic affairs, but it seems to me that colloids and their actions may be explained on mechanical principles rather than electrical, and that we are going out of our way when we assume that colloids are supported in a liquid by some electrical force acting against gravitation.

To begin with, consider emulsions, or liquids in which minute globules of oil are suspended. Let it be an emulsion of oil and water. It seems to be going a long way around to call in electric energy for an explanation of this phenomenon. Oil is so nearly of the same specific gravity as water, that it may be said, personifying it, that it hardly knows whether to sink, float, or remain suspended. Adhesion, which need be but slight, settles the doubt, so that it is apparent that the adhesion of the molecules of the water counterbalances the tendency of the oil to rise. Passing to water containing platinum in suspension, the subdivision is so extreme that the particles approach, for all practical considerations, the size of molecules, and may, for all we know, locate themselves in the interstices among the molecules of the water, somewhat as shot would among bullets and bullets among cannon balls in true solution.

Or, it is easily imaginable that the dust of platinum adheres to the water particles with sufficient force to overcome gravitation, in the same manner that any kind of dust will remain upon a ceiling against the downward pull of gravitation. Why call in electricity for these simple cases until some experimental verification is offered—unless for purposes of discussion? It is well that Prof. Whitney has brought up this question and shown the gist of the subject as it now stands.

On the other hand, a simple imaginable or old experiment seems to me to discourage the presence of electrical discharges. Let the platinum be not in almost atomical form, but tangible, say, simply a coin. Let this be attached to the end of an insulating handle or glass rod, and the coin charged either with positive or negative electricity. No sooner does the coin touch the water than the charge is dissipated; that is, distributed throughout the large mass of water and the containing vessel. On the same principle, any charge on the platinum or other "colloid" would not remain an instant after touching the water.

Electricity does not play any part in the precipitation, as far as I can see, and purely mechanical explanations seem to be more probable and satisfactory. The addition of an electrolyte in a very small quantity throws down the colloids. The calling of a reagent by the name of electrolyte is favorable to the electrical theory. There are no electrodes present, so why call the solution of salt, or other chemical, an electrolyte? It is nothing more than a liquid which will freely mix with and diffuse itself, or dissolve, in the water or that liquid which suspends the colloids. The paper shows that some of the reagent or salt solution goes down with the colloids; therefore, this is sufficient evidence that the adhesion between the colloids and the added solution is greater than that between the original liquid and the colloids. If too much reagent is added, the precipitation is interfered with, —why? Possibly, because the particles of reagent are so numerous that they scatter themselves, together with their minute load of colloids, throughout the mass as well as at the bottom of the containing vessel.

Regarding colloids approaching and receding from electrodes, because they contain charges, why is it not more easily clear that the electrodes themselves give them the infinitesimal charge necessary and then attract or repel according to well-known principles? An electroscope is actuated by a charged electrode before the electroscope is first charged, and particles floating on water will gradually be attracted to the sides of a vessel without resorting to electrical explanations. There is a chance for crucial experiments, in which a great deal of ingenuity will have to be displayed. We may now be able to say that electricity positively plays a part in dissociation by electrodes in a liquid through which a current is passed or by which a current is generated. Experiment has proved it; but that colloids remain suspended, and are thrown down by reagents by any kind of electrical force still needs proof and confirmation.

Dr. Loeb, as I remember his paper, refers to thin films of an insulator about colloids in living animal and vegetable bodies, and the puncturing of these bags lets out the electric charge from within and produces pain. I am not ridiculing his valuable speculations which, as Prof. Whitney intimates, have set others to work and have added new facts, but we generally find electrical charges on the outside of any charged mass, and not on the inside.

My interest in this subject and my theory of a mere mechanical and not an electrical cause of the phenomenon, are due to my acquaintance with a new non-electrical method of throwing down colloids, invented by a client, but still kept secret in view of obtaining patent protection.

MR. C. J. REED:—There are quite a number of interesting points for discussion in these papers, but as there are only a few with which I want to take issue, I will do it briefly.

In Dr. Sheldon's paper I think he stated that the apparatus described here is a condenser; that seems to me incorrect. It is not a condenser, but an accumulator. If we pass an electric current through zinc sulphate from a carbon to a zinc plate, or between two carbon plates, and deposit zinc, we are simply accumulating chemical energy which can be expended again in the form of electrical energy. Such an apparatus acts just as any other accumulator. A condenser, as I understand it, accumulates the electric charge. There is no evidence that anything of that kind would be accumulated here.

In another part of the paper there is a statement in regard to the production of lead by means of hydrogen.. That statement is in line with an assumption, which has been made from time immemorial, that hydrogen in a nascent state, or a state of being born, has more energy than it has in any other state Now, there has never been any proof of that, and I have never been able to find any experimental or other proof in any of the literature on the subject to show that nascent hydrogen differs from ordinary hydrogen, or can do anything that ordinary hydrogen will not do. I recently made some experiments to see whether nascent hydrogen would reduce lead from any of its compounds and I found that it would not. I found that nascent hydrogen would not only not reduce any lead, but would reduce no other metal which is electro-positive to hydrogen; that is, which combines with greater energy.

It is easy to show that lead by oxidation will produce nascent hydrogen, and if nascent hydrogen will reduce lead, why not set them both going at once and we shall have perpetual motion? Finely divided lead or tin in dilute hydrochloric acid and in contact with platinum will produce nascent hydrogen abundantly at the surface of the platinum; but if a compound of lead, such as the chloride or oxide, be introduced in contact with the platinum, there will be no reduction of metallic lead.

I think the mistake has always been in assuming that, because nascent hydrogen is produced by the same agent which simultaneously reduces the more electro-positive metals, therefore, the nascent hydrogen is the agent which does the reducing. As a matter of fact, it is only a coincidence. The hydrogen and the other substances are reduced by the same agent.

You are all familiar with the Smee battery in which zinc oxidizes and in which hydrogen is reduced on the platinum pole. There is plenty of zinc in the solution adjacent to the platinum or platinized silver plate and none of the zinc is reduced. It shows that the nascent hydrogen there cannot reduce the zinc. The same may be shown with every material which itself is capable of evolving hydrogen from any acid or liquid.

There is one point in Dr. Whitney's paper that I would like to call to your attention. He says:

"Thus far there seems to be evidence that the coagulation corresponds to the conception of a neutralization of the charges of the suspended particles by oppositely charged parts of the electrolyte."

By this I understand him to mean oppositely charged ions which have been dissociated electrolytically according to the theory of electrolytic dissociation. As I understand it, the positively charged ions and the negatively charged ions must necessarily be equal at all times in an electrolytically dissociated solution. If these suspended particles having a charge of one kind can be neutralized by the charges of the opposite ions in the solution and so become precipitated, then what becomes of the remaining charged ions? This would leave free ions of one polarity in the solution, but this is contrary to the very theory which attempts to make this explanation.

Referring to the paper of Mr. Hering on electrolytic conduction without electrodes, it seems to me that if it is possible by any means to get a continuous current, or an interrupted direct current, in a ring or chain of electrolytes, it would perhaps help us to settle some very important theoretical questions. It seems to me that if there is any possible way of getting at it, it is worth while working for. It ought to settle pretty definitely some questions relative to the theory of electrolytic association. It seems to me impossible that there could be any chemical change in a ring consisting of a single uniform electrolyte, through which a current passes without electrodes. Whether we assume that the substances are electrolytically dissociated or not, the ions must continue in the same proportion in all places.

But it would be possible, if we could get a current through an uninterrupted chain of electrolytes, to arrange several electrolytes in series, as suggested by Mr. Hering, so that certain ions could be made to move from one part of the chain into another, provided the electric current *per se* causes the migration of the ions. That is a part of the theory of electrolytic association of which I am not convinced at present.

I recently made some experiments which I cannot describe here now, but which seem to show that the migration of ions depends not simply upon the current, but upon the electrochemical action of the electrodes. For example, in a chain of electrolytes I have an isolated portion of copper sulphate with a different electrolyte on both sides of it. With a copper anode and a copper cathode, a certain amount of copper is transferred out of this isolated portion through a porous partition with a given current extending through a given time. That is, with a certain number of amperes, we get a certain number of grammes of copper transported electrolytically through a porous partition. If we make no change in the apparatus except to substitute other electrodes, which results in a different electrochemical action at the terminals of the electrolyte, we get only half the amount of copper transferred for a given amount of ampere-hours of current, and yet there is no change in the conditions concerning this isolated portion of copper sulphate. The same current maintained for the same time, causes a much less quantity of copper to pass out.

Three experiments of this kind were tried under different conditions, and in one there was a reduction of 50%, in another of 30% and in another of about 20%. I do not care to describe these experiments until after I have had a chance to repeat them with much more elaboration.

It seems to me, however, that if we consider the energy in an electrochemical action, we must come to the conclusion that, after all, the migrations are due to chemical energy only; that the electric current merely decomposes at the terminals of the electrolyte and leaves residual unsaturated constituents of the molecules which must neutralize each other by chemical action, that is, by an interchange of ionic constituents in the molecules, and that this is what causes the migration. For instance, in my conception of the transfer of copper, in copper sulphate, it is something like this: the copper ions or atoms (I make no distinction between them), may be considered as a rod of copper extending from one electrode to the other, and the SO_4 ions, another rod of SO_4 lying parallel with the copper rod. When an atom of copper is taken off the copper rod at one electrode and an atom of SO_4 is taken off the other rod at the opposite electrode, then the two rods will still be parallel, but the ends will not be even, and the chemical affinities will tend to make them even, and that will necessarily cause a motion of the copper in the one direction and of the SO_4 in the other.

MR. HERING.—Dr. Keith suggested the use of a rubber tube. He will find it stated in the paper that rubber, as well as everything except lead, is excluded by the nature of the liquid, which was highly corrosive. Concerning his remark about the diameter of the pipe, I can only say that time is too short to go into the mathematical proof here, but he will find that what I said in the paper follows mathematically from the laws of the flow of liquids in pipes and those of the electrical resistances. The laws concerning the relation of the diameter to flow of liquids in pipes, are not the same as those for the flow of electricity through solid conductors, and it is due to this difference that the relation exists which is given in the paper.

Concerning his suggested method of determining the conductivity of liquids, I think he would find if he tried it, that he would get probable or unknown errors of very large amounts. As for getting anything approaching accuracy, I think he would find it quite impossible.

There are quite a number of things in the papers of this evening which I would like to discuss, but unfortunately the time will not permit. I would like especially to discuss much of what Mr. Reed has just said, as I differ very decidedly with him in many points, but I will limit myself to the papers.

Dr. Sheldon says something about electrolytic condensers. I agree with what Mr. Reed said, that this is nothing more than an accumulator, a one-legged accumulator in this case, because one plate is dead. The action of the true electrolytic condenser, as I understand it, is something quite different from what Dr.

Sheldon describes it to be, but the hour is so late now that I cannot go into that.

Mr. Jacobs, I think, uses the words " heat " and " thermic " in a somewhat misleading sense, although the same is done by many other authors. The heat of formation, so-called, is not really heat at all; at least, not necessarily so; it is energy, which may be converted into several other forms of energy, only one of which is heat.

He shows how hydrogen may be produced cheaply and in very large quantities, but the question naturally arises, what is to be done with all of that hydrogen? Is there a market for such quantities?

Referring to Dr. Keith's paper, I would like to ask how he gets out the gold and silver? It seems to me that one of the important features in a copper reduction process is the recovery of the gold and silver which are associated with the copper, but in his method the gold and silver will go down as sludge with the large mass of the powdered rock, and therefore make a very poor gold and silver ore.

Dr. Keith:—I will say that in this particular case which I considered, gold and silver were not present in sufficient quantity to be of any commercial value.

President Steinmetz:—I may say regarding the name electrolytic condenser, that the name has been introduced and has become standard in electrical engineering terminology, for the reason that a polarization cell, as, for instance, two platinum electrodes in diluted acid, when exposed to an electric potential behave analogously to an electrostatic condenser. A polarization cell, when exposed to alternating electromotive force, below the voltage of dissociation, acts like a condenser in so far as the alternating current in the cell leads the electromotive force ninety degrees or less, (by the energy lost in the cell), and, therefore, the polarization cell has been proposed very largely as a substitute for the electrostatic condenser and is used to a limited extent.

Regarding the colloid question and the discharge of the suspended particles, this is not necessarily the case. If you say the suspended particles in the colloid solution have electrostatic charges, or as you may perhaps better express it, are at an electric potential different from the electric potential of the solution, it is not necessary that even in an indefinite time the potentials should be equalized. There is one characteristic difference in the electric phenomena from some other phenomena, as for instance, the phenomena of heat. The potential function of heat must be continuous; there can be no sudden and abrupt change of potential, or temperature, at the boundary line of two substances, but the temperature must always be a steady function of space. It is different, however, with the electric potential function. We know that in a state of equilibrium there is an abrupt change, or discontinuity in the electric potential function at the boundary line of two substances. For instance, if you have a copper and a zinc plate in water or any other solution, which does not act chemically thereon, then no chemical action will take place, and there will be an equilibrium retained forever, but there will be a difference of electric potential between the zinc and the copper. In the metal, the potential function is continuous, and in the conducting liquid between the two, it is continuous also. It follows, therefrom, that there is a discontinuity of electric potential at the boundary line between the metals in the solution. Hence, there may be in the state of equilibrium a discontinuity in the electric potential function between the suspended colloid and the liquid in which it is suspended, and this discontinuity, this difference of potential, exists and is necessary for the state of equilibrium, while any electric stress disturbing this discontinuity, or difference of potential, will cause a disturbance of the equilibrium and thereby precipitation of the colloid. For instance, introducing an electrolyte with ions which have a different discontinuity of the potential function, the difference between such ions and the suspended particles of the colloid will cause a disturbance of the potential function which may cause precipitation. So you will see it is very possible with electric potential functions to have a discontinuity or constant difference of potential existing in a state of equilibrium at the boundary line of two substances, while with other forms of energy, as heat energy, for instance, such discontinuity cannot exist.

If there is no further discussion I shall call upon the authors of the papers to conclude.

MR. WHITNEY:—In reply to Mr. Reed's question as to where the negative ion of the coagulating salt goes: this occurred to us in the experiments. If we assume negative colloids to be precipitated or coagulated by the positive ions of the salt, say barium, of barium chloride, the negative charge of the chlorine is to be accounted for. The negative charge of the chlorine must go somewhere. When the experiment was tried, hydrochloric acid was found free in the liquid. We found the barium carried down with the colloid and free hydrochloric acid in the solution. It seems to me that this in a sense explains away that difficulty. This means that the colloids act as hydrolyzing agents. The salt is decomposed, giving the hydrate which stays with the colloid and the acid which remains in the supernatant liquid.

MR. REED:—I do not see how this accounts for the precipitation of the suspended electrostatically charged particles, as it would leave free ions of one polarity in solution.

DR. KEITH:—I would like to say something on the matter of colloids. In the electrolysis of sulphate of copper solutions, using carbon electrodes, I have found that the solution was very much darkened, and that this dark solution would filter; but carbon was deposited with the copper. If carbon existed in this solution in a colloidal condition, as has been stated by Mr.

Whitney, then this colloid must have followed one of the ions, that is copper, in its deposition; or else the solution was one of carbon which was an electrolyte, and carbon was deposited by electrolytic decomposition.

DR. SHELDON:—Concerning Dr. Keith's statement relative to the increase of the critical current density, that the electrolyte must be also circulated toward the anode, I have tried a number of experiments on anodes of various sizes, and I find that the changes have no influence whatever on the critical current density of deposition.

Concerning the production of nascent hydrogen in the production of a sponge lead, whether the hydrogen is nascent or not, I do not know, but that litharge, placed on those lead electrodes, is converted into sponge lead, I do know to be a fact.

In regard to the use of the term electrolytic condenser for the cell which I have described, I need to make no apology, seeing that I have such an eminent authority as President Steinmetz on my side.

I am delighted to think that the writing of this paper has brought out such an explanation from the President of the Ampere Electrochemical Company, concerning the subject of the manufacture of camphor and artificial rubber.

MR. JACOBS:—In reference to the criticism as to my use of the term thermic conditions, what I said was that when electrolysis did take place in the electric furnace, even then the effects depended solely upon thermic conditions—what I meant was this, that in order to do work—to break up or decompose a chemical compound—you have to move against a counter force of a definite amount of energy, which is represented by the heat of formation of the compound in question. Knowing this heat of formation, the voltage required may be calculated and from that data and the electrochemical equivalent of the compound, you may find your working conditions, and determine the electrical energy necessary. In that way I mean that the results are dependent on thermic conditions, meaning energy—the energy of the chemical combination. In reference to the sale of pure hydrogen, I will not make any comment. I think uses will be found for it.

On motion the meeting then adjourned.

[COMMUNICATED AFTER ADJOURNMENT BY MR. C. J. REED.]

In the paper of Mr. Jacobs the statement regarding the energy required for the " fixation " or oxidation of nitrogen is likely to give an exaggerated impression as to the amount of energy necessary for this purpose. The amount is really insignificant and none at all is absorbed endothermically, except when the reaction takes place at a temperature above the boiling point of N_2O_5.

The formation heats of the oxides of nitrogen were investigated and published by Berthelot in 1875 (Annales de Chimie et de

Physique [5], VI., 151; 1875). He found the following formation heats:

N_2O_5,	gaseous	− 1.2	kilogram calories.
	liquid	+ 3.6	"
	crystallized	+ 11.9	"
	dissolved	+ 28.6	
N_2O	gaseous	− 20.6	"
	liquid	− 18.8	"
	dissolved	− 14.4	"
NO	gaseous	− 21.6	"
NO_2	gaseous	− 1.7	"

For the formation of N_2O_5, therefore, in the solid, liquid, or dissolved condition, no heat is required, but the reaction or combustion evolves heat. For the formation of gaseous N_2O_5, as it would be formed, for instance, in the electric furnace, there is required only 1,200 gram-calories for a gram-molecule or 108 grams of N_2O_5; that is, 11.1 gram-calories per gram of R_2O_5. This would be equivalent to the quantity of heat required to raise the temperature of a gram of water 11.1°, and is really insignificant from a commercial standpoint.

The practical difficulty in the way of direct combustion of nitrogen to N_2 O_5, is due to the very high temperature required for the ignition and the heat required to bring the reagents to this temperature. The difficulty and inefficiency of the process is further greatly increased by the fact that the atmospheric proportions of oxygen and nitrogen are very different from the proportion in which these elements combine to form N_2O_5, and that, therefore, a large quantity of unconsumable nitrogen must be raised to this high temperature and then rejected.

The proportions by weight of oxygen and nitrogen in the atmosphere are 23 of oxygen to 77 of nitrogen, while the combining proportions are 80 of oxygen to 28 of nitrogen. For every gram of nitrogen consumed, therefore, 9.6 grams must be raised to the temperature of ignition. The result is virtually the same as if the specific heat of nitrogen were multiplied by 9.6. This indicates that the successful commercial solution of the problem would be in supplying oxygen in the proper proportion, or else in bringing about the combination indirectly by oxidizing the nitrogen at a low temperature.

Another possible solution would be in producing first a lower oxide and subsequently further oxidizing it. Of the other oxides the most favorable for the production of HNO_3 would be NO or NO_2. But even in these the proportions of nitrogen and oxygen are very different from the atmospheric proportions. The endothermic absorption of 21.6 kilogram-calories in the formation of NO is of no great practical importance, as this heat is evolved again in the second process of further oxidation.

From the facts stated, it is apparent that the inefficiency of artificial processes for the fixation of nitrogen is not due to the absorption of energy in the chemical reaction, so much as it is due to the final rejection of energy in the form of unavailable heat, which escapes in the unused nitrogen.

[COMMUNICATED AFTER ADJOURNMENT BY MR. E. P. THOMPSON.]

Having opposed, in my discussion at the meeting, the electric theory regarding colloids or particles suspended in a liquid, it is incumbent that I should present a better theory if possible. I think I can dispose of all theories, and clearly prove the principle upon which this phenomenon rests. The premises are, in the concrete, that a cubic foot or cubic inch, or other comparatively large piece of platinum, will sink rapidly in water, while a piece approaching the size of a molecule—that is, a very small piece or particle, or a colloid, as termed in the Whitney paper, apparently does not sink, but remains suspended in the water indefinitely. I have performed experiments, and I find that colloids are continually sinking, provided the liquid is maintained as free as possible from circulation by changes of temperature, and free from jars of passing wagons, walking on the floor, and so forth. Any stirring or other motions, however slight, as by slowly heating the liquid, will cause the colloids to be wafted as if on wings, into the mass of the liquid. My problem to be proved is, why does a large piece of platinum sink fast and a small particle very very slowly? I decided that it was due to a less reduction of surface in proportion to reduction of mass. If people were as small as colloids, they would have no trouble in flying, because their weight or mass would be almost zero, while the surface would be infinity almost, in comparison. Birds are small animals. Even an eagle is small compared with beasts. The same is true of fish—allowing for a few exceptions. This conception and explanation assist in understanding the problem of the flying of birds.

It may be said that a molecule or atom is practically all surface. Let this be proved first by a specific converse example. Imagine a cube of platinum. It is, say, a cubic foot, There is a square foot of surface on each side, and, therefore, there are six square feet of surface. Now place another cube on top, so as to make a mass of two cubic feet. Now, how many square feet are there? Twice as many? No, only ten square feet. If in a minute particle the radius is 1/1,000 of an inch, the surface has 300 times as many square inches as the mass has cubic inches. Similar calculations will show how minute is the mass in acolloid in proportion to its surface. Consequently, it falls through the liquid on the principle of a parachute or a feather in air, or a horizontal sheet of paper in water, except that the speed is proportionally less.

The same principle explains the floating of smoke, which usually falls several feet from where it issues even in quiet air; but I can call attention to a smoke that falls twelve miles distant.

It may be seen from New York Harbor,at Bayonne, N. J.,a faint, white smoke drifting in the direction of a breeze. As far away as Westfield, N. J., twelve miles, it may be detected by the nose. It is from an oil refinery. With a Southern breeze, it is recognizable in any part of New York City. The particles of smoke are colloids in air, and the air may be ever so quiet and yet the white particles appear to be held in suspension like other colloids. It may be concluded, I think, that colloids are not truly held in *permanent* suspension, but are in the process of *sinking* in an absolutely quiet liquid, and that they do not sink fast, because the mass or weight of a particle diminishes in much larger proportion than its surface, and I conclude further, that, whether any electricity is present or not, and independently of the curious action of electrolytes upon colloids—that colloids sink very slowly in a liquid free from circulation, because the surface of a colloid is enormous in proportion to its weight.

[Communicated after Adjournment by Mr. C. F. Burgess.]

In regard to the paper by Mr. Carl Hering on "Electrolytic Conduction without Electrodes," I might add still another way for setting up and detecting the flow of current in an electrolytic conductor without the use of electrodes. Mr. A. B. Marvin, of the department of Applied Electrochemistry of the University of Wisconsin, has devised and tested a number of methods for detecting the flow of current induced in an electrolyte, a number of which were mentioned in Mr. Hering's paper, and from the results of such tests it seems very conclusive that the flow of current without electrodes is very similar in what are known as electrolytic conductors and in metallic conductors. The difficulty in demonstrating this fact lies in the enormous difference existing between the conductivities of the two classes of conductors. One of the methods which apparently bears the stamp of novelty was the introduction of a good conducting electrolyte in place of the squirrel-cage armature of a three-phase induction motor. It was thought that if a rotation either of electrolyte or the vessel in which the electrolyte was contained could be produced, it would be a demonstration of the fact that currents were set up in the electrolyte without electrodes. This was found to be the case. In rotating the field in one direction, the electrolyte began to revolve after a short time, and on reversing the direction of the rotating field, the electrolyte came to a rest and then slowly reversed its direction.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, March 28th, 1902.

The 163rd meeting of the INSTITUTE was held at 12 West 31st Street, this evening, President Charles P. Steinmetz in the Chair.

PRESIDENT STEINMETZ:—Gentlemen, the meeting will be in order. I give the floor to Secretary Pope, to make some announcements.

SECRETARY POPE:—At the meeting of the Board of Directors this afternoon the following associates were elected:

Name.	Address.	Endorsed by
BEVENUE-MILLER, EDWIN DAVID,	Electrician, Natal, Government Railways, Essex Road, off Umbilo Road, Durban, Natal, So. Africa.	W. D. Weaver. R. W. Pope. Edward Caldwell.
BROWN, HUGH AUCHINCLOSS,	General Utility Engineer, Crocker-Wheeler Co., Ampere, N. J.; residence, 285 Springfield Ave., East Orange, N. J.	Horace Dowie. S. S. Wheeler. Gano S. Dunn.
BULLEN, DANA RIPLEY,	Salesman, General Electric Co., 200 Summer St., Boston; residence, Winthrop, Mass.	Louis Bell. Harry Bottomley. S. B. Paine.
BURTON, FRANK VAIL,	Office Salesman, Western Electric Co., 463 West St.; residence, 475 Central Park West, New York City.	G. F. Atwood. G. A. Hamilton. P. G. Burton.
CLARK, EUGENE BRADLEY,	Chief Electrician, So. Works, Illinois Steel Co.; residence, 5342 Cornell Ave., Chicago, Ill.	C. F. Scott. H. J. Ryan. R. D. Mershon.
COSBY, FRANK CLARK,	Salesman, Westinghouse Elec. and Mfg. Co., 120 Broadway; residence, 124 West 114th St., New York City.	C. F. Scott. H. J. Ryan. H. W. Fisher.
DAVIDSON, JAMES EDWARD,	Superintendent, Port Huron Light and Power Co., Port Huron, Mich.	R. W. Van Vleet. Alex Dow. H. G. Field

DICK, WILLIAM AMZI,	Designing Electrical Engineer, Westinghouse E. and M. Co., Pittsburg, Pa.	N. W. Storer. C. E. Skinner. C. F. Scott.
FANSLER, PERCIVAL ELLIOTT,	Post-Graduate Student, Purdue University, Lafayette, Ind.	W.E.Goldsborough C. P. Matthews. J. W. Esterline.
FISH, FREDERICK PERRY,	President, American Telephone and Telegraph Co., 125 Milk St., Boston; residence, Brookline, Mass.	Elihu Thomson. C. S. Bradley. H V. Hayes.
FOLK, FREDERICK JACKSON,	Chief Electrician, New York and Queens E. L. and P. Co.; residence, 135 Rutland Rd., Brooklyn, N. Y.	W. B. Jackson. Harris J. Ryan. H. A. Lardner.
GRANT, OLIVER REMICK,	Student, Columbia University; residence, 2236 Southern Boulevard, Bronx Borough, New York City.	F. B. Crocker. G. F. Sever. F. Townsend.
GRISSINGER, ELWOOD,	Engineer, The Cataract Power and Conduit Co., 40 Court St., Buffalo, N. Y.	H. W. Buck. P. M Lincoln. C. F. Scott.
HALL, CLARENCE MORTIMER,	Teacher of Physics and Electricity, Manual Training School No. 1, 17th and R. I. Ave., N. W., Washington, D. C.	H B. Smith. L. D Bliss. F. R. Jones.
HODGE, CHARLES,	Salesman, Westinghouse E. and M. Co., 120 Broadway; residence, 72 E. 34th St., New York City.	C F. Scott. R. D. Mershon. P. T. Brady.
HOGAN, CHARLES WILLIAM,	Photometric Expert, Columbia Incandescent Lamp Co.; residence, 3028 Bell Ave., St. Louis, Mo.	J. E. Randall. H. B. Shaw. R. W. Pope
JOHNSON, WOOLSEY MCALPINE,	Electro-Metallurgist, Oxford Copper Co., New Brighton, S. I., N. Y.	Wm. Stanley W. L. Robb. W. D. Weaver.
KNIGHT, PERCY HENRY,	District Engineer, Westinghouse E. and M. Co., San Francisco, Cal.	C. F. Scott. N. W. Storer. C. E. Skinner.
MILLER, ALPHONSUS JOSEPH,	Laboratory Assistant, Western Electric Co., 463 West St.; New York City; residence, 161 Newark St., Hoboken, N. J.	G. A. Hamilton. D. E. Bicknell. Norman Leeds.
MURPHY, EDWIN J.,	Assistant Engineer, General Electric Co., Lynn. Mass.	W. C. Fish. F. P. Cox. E. E. Boyer.
MCALLISTER, ADDAMS STRATTON,	Assistant in Physics, Cornell University; residence, 106 Catharine St., Ithaca, N. Y.	H. J. Ryan. E. L. Nichols. J. P. Jackson.
MCGRATH, WILLIAM HENRY,	Electrical Engineer, with Stone & Webster, 930 Federal St., Boston; residence, 27 Pleasant St., Quincy, Mass.	C. A. Adams. S. E. Whiting. Russell Robb.

PHILLIPS, ELLIS LAURIMORE,	Engineer, Westinghouse, Church, Kerr & Co., 8 Bridge St.; residence, 11 West 103d St., New York City.	H. J. Ryan. J. J. Bellman. P. H. Powell.
PIERCE, ALFRED LAWRENCE,	Superintendent, General Manager and E. E., Borough Elec. Works; residence, 102 N. Whittlesey Ave., Wallingford, Conn.	A. E. Winchester. E. C. Boynton. J. B. Cahoon.
PIRTLE, CLAIBORNE,	Sales Agent for North Carolina General Electric Co., Box 301, Greensboro, N. C.	E. J. Berg. W. L. R. Emmet W. I. Slichter.
RADTKE, ALBERT AUGUSTUS,	Instructor of E. E. and Physics, R. I. College of Agriculture and Mechanic Arts, Kingston, R. I.	D. C. Jackson. B. V. Swenson. C. F. Burgess.
REYNOLDS, LOUIS EMBREE,	Chief Electrician, Independent Light and Power Co., 321 Market Street; residence, 460 Noe St., San Francisco, Cal.	W. H. Allen. G. P. Low. W. R. Hewitt.
RUGG, WALTER S.,	Engineer, Westinghouse Elec. and Mfg. Co., 120 Broadway; residence, 225 W. 83d St., New York City.	L. B. Stillwell. H. J. Ryan. B. J. Arnold.
SCRIBNER, CHARLES E.,	Engineer, Western Electric Co., 259 South Clinton St., Chicago, Ill.	J. J. Carty. B. Gherardi, Jr. J. C. Rennard.
SESSIONS, EDSON OLIVER,	Construction Engineer, General Electric Co., Toledo, Ohio; residence, Schenectady, N. Y.	C. P. Steinmetz. F. O. Blackwell. T. C. Martin.
SHERWOOD, EDGAR F.,	Superintendent of Traffic, New York Telephone Co., 18th St. and Irving Place, New York City; residence, 59 Park Ave., East Orange, N. J.	J. J. Carty. B. Gherardi, Jr. J. C. Rennard.
SMITH, WILLIAM NELSON,	Electrical Engineer, Westinghouse, Church, Kerr & Co., 8 Bridge St., New York City; residence, 62 Morris St., Yonkers, N. Y.	G. L. Hoxie. Carl Hering. Edward Caldwell.
SPENCER, HARRY B.,	Clerk in Draughting Department, General Electric Co., Lynn, Mass.; residence, Proctor, Vermont.	Elihu Thomson. N. S. Hopkins. E. E. Boyer.
WHITE, LINDEN G.,	Superintendent Electrical Department, Columbus Edison Electric Light Co., Columbus, Ohio.	C. D. Haskins. F. C. Caldwell. W. S. Barstow.
Total, 34.		

At the same meeting the Board of Directors made the following nominations for the coming election:

For President—Charles F. Scott ; *for Vice-Presidents*—C. O. Mailloux, Bion J. Arnold, Schuyler S. Wheeler ; *for Managers*—Townsend Wolcott, Gano S. Dunn, E. H. Mullin, Charles A. Terry ; *for Treasurer*—George A. Hamilton ; *for Secretary*—Ralph W. Pope.

A paper read at the 163d meeting of the American Institute of Electrical Engineers, New York and Chicago, March 28, 1902.

THE TELEPHONIC STATUS QUO.

BY ARTHUR VAUGHAN ABBOTT

It is difficult to estimate the present telephonic situation without the recitation of a little history that may appear quite trite to many.

The introduction of the telephone dates from 1876, when, at the Centennial Exposition, the Bell magneto instrument was publicly exhibited. Almost immediately the patents covering this and subsequent kindred inventions, afterward construed to cover all feasible methods for the electrical transmission of speech, passed under the control of an association, which under one corporate name after another, and in combination with its various operating and manufacturing affiliations, has been popularly collectively known as the Bell Telephone Company. The method of developing telephonic business consisted in forming a manufacturing company whose function was that of creating the necessary apparatus, and a large number of operating companies, one in each particular territory, to absorb and use, under license, this apparatus in serving the public. In all the subsidiary companies the parent organization took an active part, always retaining a controlling interest, so that the entire telephonic business of this country was, during the lifetime of the fundamental patents, to all intents and purposes, that of a single management.

The inception and perpetuation of an enterprise to operate over this entire continent, necessitating business relations of the most heterogeneous character, required the exercise of the keenest skill and shrewdness in the manipulation of men, and thus acquired the greatest advantages in uniformity, strength and coherence. Quite possibly, under any other form of organization, American telephonic development would be far behind what it is to-day, for it cannot for a moment be denied that the Bell system is a most magnificent masterpiece, both of business and technical engineering.

But with all these virtues some faults appeared. Seemingly a policy of secrecy prevailed. Telephonic conventions, initiated in the earlier days, were abandoned, or held at the rarest intervals; that freedom of speech so dear to the American mind, the exercise of which developed the later inventions of the electric light and the electric railway in a shorter period of time to a wider degree, was frowned upon even to the extent of non-technical publications. For the writer well remembers, after a popular magazine article, his general manager intimating, that good telephonists should, like small boys, be seen and not heard. Search as one may, where in our transactions will one find a paper from a professional telephonist, save Mr. Carty's classic and ancient (though classic in spite of its age) exposition of electrostatic induction? The manufacture of apparatus, particularly of transmitters and receivers, was sedulously guarded and the magneto bell, the receiver and solid-back transmitter stand today, after one or two decades of experience, unchanged and unimproved.

Nor was technical reticence, and consequently impeded progress the only consequence. Gradually, in the public mind, arose an undefined feeling that something was wrong with the telephonic "*quid pro quo.*" Alleged extortionate charges, coupled with complaints of poor service were whispered about. Legislative and aldermanic investigating committees were appointed that resembled the fabled characteristics of the month of March, for they went to work like lions, only in due process of time to subside into the most lamb-like serenity. People saw only an insignificant bit of apparatus which their common sense told them could be made for a dozen dollars, for the annual use of which a charge of from $50 to $250 was made. Small wonder, then, in view of this insufficient evidence, that on the expiration of the fundamental patents, there were hosts of enterprising electricians, many of them of the locksmith and bellhanger type, who were ready to flood the market with telephonic apparatus of all kinds, good, bad and indifferent; or that there was a public trained and educated to embrace any telephonic relief from the real or fancied oppression of a so-called grasping monopoly. It is no part of the present paper to examine into the validity of the grounds for this state of public sentiment. But it exists, deeply and strongly rooted in the public mind, fixed therein by nearly a score of years of most unfortunate training; so firmly seated that in some cases independent exchanges, charging regular rates, have flourished and grown fat in the face of absolutely free service offered by the older company, in the hopes of crushing by the superior endurance of a powerful backing, its younger and seemingly weak rivals. So strong is this sentiment that to-day, though the Bell companies are nearly a quarter of a century old, and the independent companies barely six years, the field is quite evenly divided between them as is shown by the statistics in Table I.

TABLE I.

ITEM.	BELL EXCHANGES.	INDEPENDENT EXCHANGES.
Invested capital..............	$320,000,000.00	$150,000,000.00
Number of exchanges	1,500	2,811
Sub-stations..................	1,080,000	1,198,000

During the past year about $18,750,000 has been spent on telephone apparatus, of which about 40 per cent. is credited to the independent interests, and in this field 415 new independent telephone companies have been floated.

So far as apparatus is involved, there are to-day a number of firms that can, and regularly do, produce transmitters and receivers whose clearness and volume of articulation cannot for a moment be considered to be inferior to those manufactured by the older corporation. There are at least two companies that are prepared to, and do manufacture as broad and variegated a line of switchboard apparatus, are well equipped, do as good work, attain similar results, and are supplied with electrical talent equal to that of the Bell Company's. So, it is possible to-day for anyone to build a first-class telephone exchange, and with good care, shrewd and expert management, to give service that cannot be excelled at the lowest possible price. Such, I say, is possible, but, unfortunately, it is rarely done. On the contrary, a very erroneous idea prevails in the mind of most of the independent companies as to the requirements and limitations of telephony. A large portion of those interested therein seem to have been bitten by a kind of telephonic tarantula until they feel that a telephone exchange is a sort of Golconda. Put it in and it will run itself, rolling in dividends in a way to make the goose which laid the golden egg blush for incapacity. According to their doctrine, all one has to do is to put in a telephone (any kind of a telephone) build a line (any kind of a line), set up a switchboard (any kind of a switchboard), go away and leave it to its own devices, returning once a year to collect the dividends. For instance, the general manager of a 5,000 line independent exchange recently remarked in answer to a question as to cost of maintenance, "why, we don't have any maintenance, we have a new plant." And another man, president of more than one telephone company, laughed me to scorn when I advised him to allow $2 per sub-station per year for maintenance expense, averring that ten cents per year was amply sufficient for the purpose.

Another and more vicious result of such misconception. is the way in which new telephone companies are floated. Half a dozen of the prominent citizens of some town conceive the idea of establishing a telephone exchange; an ordinance is rushed through the City Council of which one or more of the "prominent citizens" are members, a company is formed, enough stock subscription raised to pay current office expenses, and the labor of erecting a few miles of wire. The switchboard and a lot of material is purchased on three months, six months or a year's time, a few subscribers connected up, and lo! a full-fledged telephone plant is in existence, which the incorporators now proceed to mortgage to some confiding trust company, using a good block of stock as tempting bonus, securing to themselves a nice profit, and incidently getting funds to pay for the switchboard, and other material previously purchased on credit. How mistaken are these ideas, the first financial cold breeze that blows over this country will surely demonstrate. Indeed, the preliminary puff is already felt as is testified by the present lamentable financial condition in Cleveland, for if ever the true epitaph is written over the unfortunate Everett-Moore syndicate it will read, "Died of too much telephone."

Such a condition of affairs is partly due to unprecedented prosperity in America, but it must not be forgotten that both prosperity and poverty progress in cycles. We are now about at the crest of the present prosperity wave, and in the flush of plenty and success, men grow careless and plunge wildly into all sorts of enterprises. Oh! for some Joseph that could rend aside the veil, and show the lean and hungry years of the future waiting to devour the sleek and well fed ones of the present. But, more than all, the public has been educated to regard the telephone from an entirely false standpoint, both as regards the instrument itself, and the annual charge for its use. I do not believe that one per cent. of the population of New York City have ever seen a switchboard, or that one-tenth per cent. have the slightest conception of the maze of circuits that traverse the streets. How many of us, electrical engineers though we are, and so presumably familiar with at least the rudiments of telephony, know anything of the tortuous path traversed by the messages we send a dozen times a day from our desks? By the formerly universal flat rate system, a certain charge per annum was made for each instrument, and this method indissolubly linked the telephone instrument with the price charged. This is a false unit, and the erroneous impression thus created in the public mind will take years of sorrowful and patient eradication. It is not the instrument, but telephonic service that the subscribers pay for; not the transmitter and receiver that stand on the desk only, but the conduits, cables, switchboard, trunk line plant, the operators who patiently, night and day, await an instantaneous summons, and all the other complicated paraphernalia that complete an extensive business organization. All these and more are included in the necessary cost of service, and if only the cloud of mystery that has for so long obscured telephonic practice were dispelled, and the public taken fully into the confidence of the operating company, much of the present friction would be obviated. People would gain not only true appreciation of the service performed for them, and so be more tolerant of tariffs, but would also acquire such a knowledge of the telephonic *modus operandi* as vastly to increase the efficiency of every telephone plant. In this respect, the independent companies are setting an admirable example. Frequent conventions take place at which free and open discussions of all subjects of interest are held, to which all, whether friend or foe, are equally and cordially welcomed. Each week the technical papers of the land chronicle all items of progress in so free and full a manner as to display the most striking contrast to the years of grim and forbidding silence maintained by the older organization.

There appear to be five results that are certain to follow:

FIRST: Many of the present organizations lacking in experience and strength, located in unpromising fields will go down with the first monetary stringency, throwing by their ruin considerable disfavor on the financial aspect of telephony.

Second: The remaining independent companies will be forced to adjust their rates until such a point is reached as to enable them to become investments of reasonable earning power, and to this end only the most carefully designed, best constructed and most shrewdly managed plants can possibly survive.

Third: The rates of the Bell companies must fall until both the Bell and the independent companies meet at a common level and thereafter, so far as the public is concerned, it matters little which gives service.

Fourth: The independent companies are weak in their lack of coherence, feeble in possessing but few exchanges in the larger towns and almost none in the great cities, and powerless in the toll and long distance field. New York is the keystone of the telephonic arch, and when that city is captured by an independent company, the battle will be more than half won, but judging from recent developments in this direction, that time is still in the somewhat far distant future.

Fifth: An extensive and far reaching tariff revision is the vital question of the present. If the Bell companies heed the tendencies of the times, they may yet not only retain, but revive a fast diminishing supremacy. Failing in this respect, they will be forced to meet this just demand, either by the struggle for existence in the face of fiercest competition; or by the pressure of ordinance regulations, as has recently been witnessed in Chicago; or by such legislative action as will declare all telephone companies to be common carriers, and compel each to handle and transmit to its own subscribers any messages delivered by the other.

In possession of a country of unbounded resources, the American public is of all peoples the easiest and most tolerant to deal with. It has made money and it expects and wants everyone else to do likewise. It is good-natured and somewhat careless as to what it pays, provided good goods are returned, and charges that are equitable and just to all are made. But woe betide those who attempt to get something for nothing, or to discriminate unfavorably between different portions of society. Their fate is certain.

It is this innate feeling that has instituted the revolt against the flat rate system. One does not contract by the year with the milkman for all the milk the family can drink, nor with the baker or butcher for all bread or meat, nor with the gas company for all the gas one wishes to burn. The electric light people even go so far as to install a demand meter, scaling bills not only upon the quantity of electricity used, but considering also the time at which it is asked for. To charge a subscriber who makes 100 messages per day the same rate as one who makes 10 is obviously unfair, and driven from the illogical flat rate system, the plan of an initial charge, plus a message rate for all calls beyond a certain annual number, has gained considerable currency. That this is an improvement and more just than the former method cannot be gainsaid, but even this scheme contains large elements of manifest injustice, for the message is no more the true unit of charge than going to a livery stable and hiring a carriage to take a drive would be a fair basis for the liveryman, for one customer might be gone an hour and another all day. The average length of telephonic conversations is about two minutes, but averages are dangerous. In one case under the personal observation of the writer, a young bride on her return from the honeymoon kept the line leading to her mother's house busy for several consecutive days for more than 40 minutes at a time. Query: shall the bride be charged ten cents for her call and you the same price for a two-minute conversation? No; the message rate system, while approximating more closely to the truth than the flat rate, is still on a false basis and should be corrected.

In giving service, telephone companies do three entirely separate and independent things which are incommensurable with each other, all of which every just and equitable tariff must recognize and express.

FIRST: The telephone company supplies and maintains a certain amount of apparatus necessary to connect each subscriber with the central office. This apparatus must be furnished and cared for whether used or not, merely to give the subscribers an opportunity to call. The quantity and quality of this apparatus does not vary with the load, being the same whether the instrument is used once a year or 100 times a day. A flat rate annual tariff sufficient to pay interest, depreciation and maintenance on this portion of the plant is fair and just, and by recognizing varying lengths of subscribers' lines, this charge may be made exactly proportional to the requirements of each station.

SECOND: The telephone company must maintain a corps of operators to answer subscribers' calls and to perform the necessary avocations of connecting subscribers together. This

TABLE II.—GENERAL TELEPHONE STATISTICS.

	Name of City.	Population.	No. of Telephones.	Per cent. of Telephones.	Wire Miles: Underground.	Wire Miles: Aerial.	Wire Miles: Total.	Wire Miles: Per Telephone.	Tariff, Flat Rates, Business Telephones: 1 Party $	2 Party $	4 Party $	Multi Party $	Flat Rates, Residence Telephones: 1 Party $	2 Party $	4 Party $	Multi Party $	Measured Service, Business Telephones: 1 Party $	2 Party $	4 Party $	Multi Party $	Excess Call $	Com. Box $	Measured Service, Residence Telephones: 1 Party $	2 Party $	4 Party $	Multi Party $	Excess Calls $	Com Box $
B	Baltimore	507,000	6,300	1.25					125	100			100	78	60						.c6		1000 c 72	1000 c 62	1000 c 48		.04	
I	"	"	6,000	1.25	1,140	757	1,897	.3	48	42	32		36	30	24							.05				365 c 18.25	.05	.05
B	Boston	560,892	23,106	4.1	47,000	7,400	54,400	2.3	162	141			116	102			1000 c 90	1000 c 75	1000 c 66		.04		1000 c 90	1000 c 75	1000 c 60		.04	
B	Buffalo	352,219	9,449	2.7	6,830	5,475	12,305	1.3									1000 c 70				.c6		1000 c 52					
B	Chicago	1,698,575	37,969	2.2	108,633	33,190	141,823	3.8	175				100	75	60		1000 c 92	1460 c 73		1000 c 48	.05	.05	1000 c 92	1460 c 73	1000 c 48	365 c 18.25	.05	.05
B	Cleveland	381,000	13,744	3.5	28,623	13,119	41,742	3.2	84	72			60	48			1000 c 60	1000 c 48	1000 c 36		.03	.05						.05
I	"	"	9,000	2.4	9,000	4,500	13,500	1.4	48				36									.05						.05
B	Columbus	125,560	8,50[illegible]	6.8	7,964	8,164	16,128	1.9	40				24															
B	Indianapolis	169,000	4,537	2.7	9,600	12,500	22,100	4.8	40				24															
B	Kansas City	163,000	7,200	4.4	6,500	7,500	14,000	1.5	96	75	51		72	60	42		1000 c 72				.05	.05						.05
B	Louisville	204,731	6,604	3.2					96	78	48	36	60	48	30	18	1000 c 74				.05						.015	
I	"	"	5,000	2.5					48				36															
B	Minneapolis	202,000	9,025	4.5	11,859	7,655	19,514	2.15	84	72	54	18	60	48	36	18	1000 c 72	1000 c 62	1000 c 48		.03		1000 c 60				.03	
B	Milwaukee	285,000	8,900	3.1	12,529	5,559	18,088	2.0	96	72	60		60	48	36		1000 c 68	1500 c 60	1000 c 50		.08	.05	1000 c 48	1000 c 36			.08	.05
B	Nashville	86,000	3,498	4.0		1,030		.29	84	48	36		54	36	24		1000 c 41				.05		1000 c 33				.05	
B	New Orleans	287,000	6,000	2.1					120				60															
B	New York	1,850,000	63 975	3.5	152,807	2,455	155,262	2.25	240								1000 c 99	1000 c 87			.08		1000 c 90	1000 c 87	1000 c 78		.07	
B	Omaha	102,000	3,851	3.7	3,571	1,758	5,326	1.4	90	72	48	24	66	48	36		1000 c 72				.04		1000 c 72				.04	
B	Philadelphia	1,400,000	23,438	1.7	72,618	7,808	80,426	3.5	160								1000 c 78	1000 c 66			.05		1000 c 69	1000 c 60	400 36		.05	
I	"	"							80	52			48	36														
B	Pittsburg	451,512	11,986	2.5	22,388	13,227	35,615	3.0	125	100	80		100	80	60		1000 c 70				.04		1000 c 70				.04	
B	Rochester	162,608	4,200	2.6	11,550	800	12,350	3.0	94	64			36	24			1000 c 70				.06		1000 c 36				.04	
I	"	"	4,800	2.6	3,324	2,011	5,335	1.25	48				30	24														
B	San Francisco	342,000	29,735	8.5	23,565	7,100	40,665	1.4					66	60			1000 c 140	1000 c 104		365 c 18.25	.05					365 c 18.25	.05	
B	St. Louis	575,238	7,851	1.4	8,465	11,940	20,405	2.6	150	100			72	48			1000 c 69	1000 c 57			.04		1000 c 57	1000 c 5			.04	
B	St. Paul	166,000	5,715	3.5	7,356	3,297	10,653	1.9	84	72	54	18	60	48	36	18	1000 c 60				.03						.03	
I	"	"	1,314	.8					48				10															

NOTE. This table is compiled from various sources, and is believed to be fairly accurate within about six months. In the first column the "B" and "I" signify Bell Plants and Independent Plants, respectively. Under Measured Service the letter "c" signifies "Calls."

expense is directly and only proportional to the number of times each station calls.

THIRD: During each conversation, battery is supplied to the subscribers' station for talking, cords, plugs, trunk lines and other common apparatus is in use, the amount and cost of which is proportional to the length of time of conversation.

Therefore, any telephone tariff to be fair to all, must recognize these three factors, and in so far as any one is omitted, and a blanket charge substituted therefor, injustice will be done, depending on how far the service rendered to a particular station departs from the general average.

To perceive the bearing of this proposition, consider for a moment the cost of installation and service. According to previous telephonic policy, the ratio of the number of telephones to population is very low, as is shown in Table II. Consequently, the installation cost per station has been high. In large cities this has varied from $150 to $250 per station. In medium cities, of say 200,000 population or so, from $90 to $125, while even in the smallest towns it is rare to find a cost of less than $50 per station. Of the installation cost, from $10 to $25 is required at the sub-station, depending upon the character and difficulty of wiring. From $15 to $50 for the switchboard, varying with the type of board, size of multiple and percentage of trunking, while the wire plant has absorbed the balance; but if by a more liberal policy the use of the telephone could be so stimulated as to raise the population ratio, to say 15 per cent., it would be possible, even in such a city as New York, to install a telephone plant at a cost not to exceed $60 per sub-station, as is shown in Table III.

TABLE III.

Probable installation cost per station of a telephone plant, sufficient to serve 15 per cent. of population.

ITEM.	COST.
Sub-station Apparatus	$15.00
Wire Plant, Subscribers' Lines	14.00
Wire Plant, Trunk Lines	7.00
Switchboard Apparatus, Subscribers' Lines	12.00
Switchboard Apparatus, Trunk Lines	6.00
Total	$54.00

Assume now that an installation charge of $15 per year per sub-station were made against each one-party line to cover interest, depreciation and maintenance, $10 per year per station each against two-party line and $8 per year per station against each four-party line, and that a charge of one cent was made for each time the central office was called up and one-half cent for each minute of actual time that the telephone was in use. Large business houses and the best class of residences would take one-party lines. Smaller business houses and medium residences two-party lines, while the bulk of subscribers would use four-party lines; all of these being arranged with selective signals and lock-outs to secure the best quality of service. Simply to illustrate the effect of this system of tariff, assume one-party lines to average ten calls per day, two-party lines seven and four-party lines three. Under these circumstances, one-party lines must bear a tariff of $75 per year; two-party lines $52 and four-party lines $23. According to this suggestion, the annual cost of maintenance and depreciation on plant would be cared for by the annual flat rate charge, which, for this purpose, is sufficient in a properly installed and maintained plant. The receipts from traffic would average $20 per thousand calls, while the actual expense should not be over $7 per thousand calls. The difference of $13 would be ample to pay reasonable general expenses and dividends. At each sub-station, a meter would be installed, carrying two dials, one showing how many times the exchange was called, and the other the total time expended in the use of the telephone. This meter should be in plain sight of the subscriber, so that he, at any time, could check the readings with his own watch. Such a device could be made and installed at an expense not to exceed $3 per station. Each station would be charged for exactly the service rendered, and it would be optional with all to regulate charges to suit their wishes.

It is probably an impossibility to make any one method of charging absolutely universal, any more than it is feasible to crowd all passengers on a railway into one car. There must be Pullmans, coaches and emigrant cars. So every telephone company must probably supply a few flat rate instruments, many meter rates and some coin boxes. "*Chacun à son goût*," but the main idea is that of producing a rate that will be absolutely just, and be capable of so stimulating telephonic business as to place an instrument in every house. Each community contains some chronic objectors whom it is impossible to satisfy, but setting such aside, it seems that a scheme of this general nature would go far toward smoothing out the existing friction between the operating companies and the public.

But with this discussion of the commercial aspect, the engineering side must not be entirely forgotten. Two very curious tendencies are observable. Among the older companies and the most advanced of the independents, those to whom experience has read some bitter lessons, there is a very strong inclination to design plants with the utmost care and skill, using the widest and best experience for the purpose, and foreseeing the future as far as possible. This is in marked contrast to the practice of a decade ago, when telephone plants, like "Topsy," simply grew, and in many respects were not unlike the dark heroine of Uncle Tom. But with the newer and less experienced of the independents, there is a most conspicuous absence of design. Because some farmer has talked half a dozen miles over barbed wire fences, a lo tof little telephone companies have immediately built toll lines of No. 10 or even No. 14 iron wire, on poles about as large as a walking stick, with grounded lines, through trolley towns, and wonder why their subscribers complain of poor service, or that their lines go down with the first snow.

Conduit construction has settled into pretty well recognized channels, involving chiefly the use of vitrified clay pipe, particularly the multiple duct forms. Periodically, a new and improved form of duct material appears destined to supersede all others, but I notice the tile men serenely go their way, and their output to-day is larger than ever.

The construction of aerial lines is rapidly becoming systemized and proceeding under standard specifications, the tendency of which is to build the lines much more efficiently and much more solidly than in the past, and to restrict the use of open wires to three or four cross arms.

There is a notable tendency to increase the size of cable. Formerly 120 pair was standard for underground work and 25 for aerial, but at present 200 pair is becoming almost universal, and even 400 pair has entered the field underground; while aerial cable has grown so that 150 pair is not unknown. For trunk lines and toll work, large conductor, low capacity cables are to the front, even to the extent of using No. 16, No. 14 or even No. 12 wire, with capacity of from .06 to .05 m. f. per mile. In switchboard practice, the common battery automatic signal board is rapidly expelling all other forms and soon will apparently reign supreme, for at present there is not a shadow of a rival looming on the telephonic horizon to dispute its supremacy. While switchboards of this type are a vast improvement over those of older construction, they still leave much to be desired, and the entire telephonic fraternity awaits with open arms the coming of the perfect switchboard. There are many who believe that a purely automatic board will offer the desired solution, but during the past decade the progress in this direction has been almost infinitesimal. A central office seems to be one of those things that need the human element, and cannot be made purely mechanical. Possibly the recently invented Faller mechanical operator may form at least a partial solution.

For the sub-station there is no progress to report. The transmitter, receiver and magneto have remained *in statu quo* for ten years, save that each manufacturer dresses his apparatus in a newer and possibly more fanciful design. This is strange when is considered that actual telephonic efficiency is less than two per cent., and that a very slight improvement in this direction would be hailed with delight by all, particularly by those who do much toll work. Part of the difficulty lies in the electrical characteristics of the line, and for this Dr. Pupin's epoch-making discovery is supposed to be a remedy, but as yet results from practical experience therewith have not been reported.

In the light of the present, what is the earnest of the future? Despite the hints of our friends of the Hertzian waves, there is nothing at present to suggest any radical discovery in the telephonic field. On the other hand, the art is gradually settling down to that inevitable and comfortable basis wherein sound financial judgment as to the expediency of a telephone plant, skillful engineering in design, the best possible construction, good business management in operation, fairness in the tariff and in the treatment of the subscriber, will be absolutely essential to produce a good balance sheet. Toward this haven strongly sets the current of popular opinion, aided by those who are most broad minded and liberal in the business. May the art safely reach this port, avoiding both the Scylla of a disastrous rate war and the Charybdis of financial wreck from rash, ill-advised investments, systems poorly constructed and operated.

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TELEPHONE RATES FROM AN ENGINEER'S VIEWPOINT.

BY FRANZ J. DOMMERQUE.

Reviewing the present method of charging for telephone service, it is found that previous to the independent movement, the Bell licensees had a free hand and were in a position to obtain the highest rates. With a competitor in the field charging lower rates, the old companies had to find some means to meet this competition and to retain at the same time the old revenues. Three methods of charging for service were introduced besides the old time flat rate; namely, measured service, pay stations and party line service. The introduction of these three additional kinds, however, deteriorated the service given to the public. The independent companies did not imitate the Bell licensees in their charges,but kept to the flat rate exclusively,distinguishing, however, between charges for business houses and for residences, thereby not impairing service. This seemed fair to all parties concerned, because the amount of work to be performed by an operating company justified a reduction in rates for residences, as the average number of calls per day from a residence subscriber is less than from a business subscriber and, consequently, the number of operators required for residence service is less than for business service. Experience quickly demonstrated that the arrangement for more than two parties on one line was not liked by the subscribers. Measured rate and pay-station service had the appearance of justice, as the subscriber paid for each call he made and thus could not find fault with the company. Naturally, he became careful in the use of his telephone, thereby reducing his number of calls to a minimum and, to some extent, the company was the loser, as it had to provide a sufficiently large plant and count the number of calls, either by mechanical devices or by writing out tickets; the latter being probably the method most in vogue. The writing of tickets is cumbersome and reduces the efficiency of the operators, and besides, is apt to make the subscriber suspicious of over-charge, as the subscriber has no control over the operator. However, the public gained an advantage in not having to pay an exorbitant rate for a small number of calls, but the rate per call was still high, as the telephone company made the measured rate correspond to the decrease in the number of calls.

It is a well-known fact that the greater the plant, or rather, the more subscribers that are connected with one and the same exchange. the higher the rates. Seemingly the subscriber in a village has the advantage over the city subscriber. The rate in the village is, say one or two dollars a month, or from $12 to $24 a year, while the city man pays $50 or more. But the villager reaches for his $12 only, say 100 subscribers, and in order to reach as many subscribers as the city man does, he will have to talk to other villages and, perhaps, over his whole county and pay toll charges for the privilege. Thus, to compare the rates the number of people reached must be taken into consideration.

Service given by small units, as in the case of a village, is considered cheap, and many can afford a telephone in a village, that could not in a city. Should it not be possible to arrange city service on the principle of village service and give every subscriber a comparatively low rate without resorting to means that deteriorate service? One step in that direction has been made already by establishing so-called private branch exchanges. We find as an example, hotels with telephones in every room for the use of the guests, the guests not paying for such service as long as they do not call for a party outside of the hotel, a small charge being made as soon as connection through the telephone exchange is desired. Such small units could be established in a great many large buildings in our large cities; a still better field for same would be found in the residence districts of our cities; usually the wealthiest classes congregate in the best localities where real estate or rent is high. The less fortunate members of the community choose less expensive quarters and so on down the scale of means. Accordingly, there are villages, so to speak, of the aristocracy, villages of tradespeople and the workingmen's villages. In each of these villages a great number of telephone calls would be for people of the same village, and a flat rate could be established for such local calls that should not be much higher than the rate of the country village, and whenever a call is made outside of the local district, a small charge could be made per call, just as the country villager pays a toll charge. This would, it is true, involve again the making out of tickets, but only to a limited extent and would not involve so much labor by far on the part of the operator as when a ticket had to be made out for each and every call in the whole exchange. In the center portion or business district of cities there will be one large office, or in very large cities, more than one, to which individual business telephones are connected. But the business man in a city transacts such an amount of business that a reasonably high charge for the unlimited use of his telephone would be, and in fact is, gladly paid as long as the service is good. However, here too, a sub-division could be made by the use of two-party line service, which is not objectionable, as it does not deteriorate the service in general, being selective, i.e., either of the two parties may be called without annoying the other party by ringing, and two not very busy subscribers will not be inconvenienced by having to use one and the same line, for only in rare cases will both parties call just at the same time, which would happen frequently, however, with four or more parties on the same line. Thus, two business subscribers, each having not enough business to demand the exclusive use of one line, could share the line and thus reduce charges.

Such an arrangement as outlined above would tend toward large offices in the center of cities and smaller offices in the residence portions, and the engineer would have to lay out his plans on somewhat different lines from those which he is used to now.

Measured service introduces also a large amount of bookkeeping, which would be done away with if only flat rates were charged.

The method of charging and collecting monthly introduced by many independent companies is another hardship for the accounting department and should not be encouraged. A subscriber who wants service and wants it honestly cannot object to paying quarterly. A subscriber who delights in the one-sided economy of moving at the end of the month to unknown quarters, thereby cheating the telephone company and landlord alike out of a month's rent, is not a desirable customer in any sense.

The scheme of charging for telephone service would therefore be as follows: (1.) For the business portion of cities a flat rate to all busy subscribers, and a reduced flat rate to less busy subscribers using a two-party line. Pay stations, of course, cannot be dispensed with, but should only be used in certain quasi public places so as to give transients an opportunity of telephoning without having to intrude upon the regular subscriber. (2.) In the residence districts, flat rate for local calls with measured service for trunk calls. Here, also, two-party line service can be used probably to still better advantage than in the business portion and would double the capacity of a small residence district switchboard.

With more than one office in the business district of a very large city, the flat rate would be different in the various offices and would correspond with the average number of calls originating in the offices. A measured rate for trunk calls in addition to a flat rate for local calls should be made, I think, only outside of the business district where the total number of originating calls is low. This trunk charge would have another beneficial effect, as it would cut the calls in busy offices down to the lowest amount and thus help to keep down the trunk expense in such busy offices, which would not be the case, if the residence district subscriber, who usually is not pressed for time, could make as many trunk calls as he pleased under a flat rate.

One more word on the subject of measured rates. It is said that it is the fairest way to charge the public for what service it actually receives, and comparison is made with the charges for electric light and gas service. There is a fallacy in such comparison, because in electric light service as well as in gas service, reservoirs store the energy, i.e., accumulators in the case of electric light supply and gas tanks in the other case, take care of the peak or peaks of the load curve, while in a telephone plant we cannot store the energy developed by the operator, and must build our plant large enough for the highest peak of the load curve and therefore have, for say 22 hours of the day, a plant on our hands that is used at low efficiency. Thus the same switchboard equipment and a line has to be built for each and every subscriber whether he calls once or one hundred times a day. It is, therefore, no more than correct to charge a flat rate, allowing certain modifications, as the two-party line rate, and regulate the flat rate according to the plant and service required. Size of plant and number of operators being purely a function of the number of calls, the flat rate should be proportional to the number of calls.

There is another incongruity in the comparison. In electric light and gas meters the quantity of energy supplied or the time of duration of supply is measured, so that each consumer pays exactly for what he receives. In measuring telephone service, no account is taken of the time or duration of conversation, but the number of calls only is recorded. It is true that for local calls, i.e., for calls between subscribers connected to one and the same switchboard, duration of conversation does not noticeably influence the operating labor and thus would not enter into the question of charge, but for trunk calls, i.e., for calls that have to be transferred from one operator to the other, it is different. For local calls, one and the same subscriber is always connected to one end of his line and different subscribers may be switched onto his line; the subscriber may use his own line as long as he pleases. as nobody else would use it anyway. In the trunk line case, no subscriber is permanently connected to the trunk line and therefore subscribers may be switched onto either end of the trunk line, whenever the trunk line is free. Thus a trunk line (and toll and long distance lines the same) may be kept "loaded" all the time and it is clearly seen that the duration of conversation over trunk lines is an important factor and regulates the number of trunk lines, trunk sections, trunk operators and everything pertaining to it. This circumstance is well taken care of in toll and long distance charges. Therefore, a measured service for trunk calls seems justified and there might be also a time limit to trunk calls, but probably it would involve more labor on the part of the operator to take account of the time than the additional income would warrant; the case of toll and long distance lines is different, as great capital is invested in such lines, these being very long, while ordinary trunk lines are comparatively short.

So much about the kinds of rates. A few words now remain to be said as to the amount to be charged.

The easiest way to determine the charges, is to make them as high as the public will stand; but with competition in the field this method is excluded and the charges must necessarily settle down to a point where service can be given at a reasonable rate to the public, leaving a fair income to the operating company.

Under the Bell regime, the charges for telephone service are undoubtedly high enough to give a handsome profit to the operating company, while many independent companies have made the mistake to start in with too low rates. In order to determine the correct rate that should be charged to assure the operating company a reasonable profit, all items that are involved in the annual expense should be closely calculated. The depreciation factor on the plant should not be taken too low, as there are so many unforeseen incidents such as blizzards menacing pole lines, new inventions making switchboards obsolete, etc., that may deplete the treasury in a short time. The allowance for depreciation should not be below ten per cent. on the switchboard; 15 per cent. on open wire pole lines; 4 per cent. on conduits; 12 per cent. on cables.

When figuring on the cost of operation, it must be taken into account that not only the salaries of operators working at the board, but also the salaries of chief operators, monitors, night operators, office managers, repair men, matron, janitor and messengers, as well as the salaries of the clerical force directly connected with the operating department, must be taken into consideration. The salaries of the officials of the company, as well as the taxes that have to be paid, are to be charged under the heading of fixed charges. A reasonable amount of rent must be charged, and in this point care should be taken not to make the figure too low, as it is often found afterwards that the rent to be paid for the best location of the office is high, because the owner of the property has found out how desirable his property is and charges accordingly.

In estimating upon the cost of the aerial and underground construction, a good many local circumstances have to be taken into consideration, as the formation of the soil, whether it is favorable or unfavorable for the setting of poles, etc. In the case of underground conduits there are obstructions to overcome, the streets in many cities being filled with all kinds of pipes so that it is very hard to lay additional conduit. I remember that in the city of Chicago, an amount of $1.20 per linear foot was added to the cost of the underground conduit in a certain street on this account.

As far as the maintenance of the plant is concerned, the figures should not be taken too low. Of course, on underground conduits the maintenance means very little, while on aerial lines it may be as high as $25 per subscriber per year.

It is impossible to give a general figure for all the items constituting the annual expense of the telephone plant, as size, as well as natural conditions of cities, differ. It is the work of the engineer to determine in every case all the items and make an estimate which is not too low, but at the same time economical.

In many cities lately, the administration, in giving franchises to independent companies, has taken advantage and forced the new-comer to accept the most severe conditions, and even has gone so far as to fix the rates. If a city takes it on itself thus to restrain a company, it should have investigated closely the probable cost of giving service, and should have done this under the advice of a telephone engineer who is thoroughly familiar with laying out telephone plants in general and with the city under consideration in particular. If the city administration fixes the rates, it is no more than fair to demand that the city administration make public the estimate upon which it bases such rates as it has fixed, so that an opportunity may be given to the franchise-seeking company to point out in what particulars such an estimate may be unfair or even incorrect.

A paper presented at a Meeting of the American Institute of Electrical Engineers, Chicago, March 28th 1902.

TELEPHONY.—1902.

BY ANGUS S. HIBBARD.

It is apparent to any one familiar with the subject that at the present time the telephone in the United States, both in a technical and a commercial sense, is advancing at top speed. in a course of development whose limitations no one will attempt to forecast.

Retarded originally by the then best known system of charging for service, the so-called flat rate which, in providing for patrons of the same class, one line, one telephone and unlimited service necessarily exacted as much from the smallest as from the largest user, the growth of exchanges throughout the country was comparatively slow. This may have been for the ultimate good of the service generally, for, during this period, it was possible to devise and test out the many combinations of operating appliances which have resulted in the standardized apparatus of 1902. Ten years ago no one conceived of the elaboration and comprehensiveness of the plant which makes the present day service possible. In hundreds of exchanges the present daily traffic could not, with the same number of lines and instruments, be carried on with the apparatus in use ten years ago.

Automatic signalling appliances, meaning the control by the subscriber with his telephone switch hook, of the operating signals necessary for call, recall or disconnection, and the central station or common battery used for all signalling or talking, have made possible the rapid and certain operations now essential to the service.

The long-distance lines, first developed around local centers, in this period were gradually pushed out until the ends met in every direction and the exchange, once local, became almost national in the extent of service possible to the user.

At this time it had been demonstrated that the most satisfactory and universally popular unit upon which to base charges for service in large exchanges was the message; and upon the introduction of that basis of charging, and especially by the arrangement of the patrons' apparatus so that payment might be made at the time service was rendered, exchanges in all the prominent cities in the country began to grow at a phenomenal rate. The telephone was no longer a luxury, limited to the service of a selected few, but, being made available to all classes of users, large and small, became an agency of greatly extended usefulness throughout the entire community.

Just as rapidly as it was possible to provide for the service to be rendered, classes of rates were made which were availed of by the public in ever-increasing numbers extending even so far, in some cases, as to the patron who may use the telephone not more than once a day.

It is needless to say that engineering and construction forces have been taxed to their utmost to keep pace with such a growth. Subway plans which had been considered sufficient for many years' future growth were, in some cities, doubled and trebled in extent. Permanent exchange buildings were erected and equipped with the greatest possible speed. Cable plants were increased in respect to the mileage of wire, in a number of cases more than one hundred per cent in one year.

The figures of the year 1901 present a remarkable study. In New York (Manhattan) the total number of telephones reached 69,361. In Chicago the net growth for the year in the number of telephones exceeded the total number operated at the beginning of the year 1898. In the San Francisco exchange, 30,214 telephones were in operation at the close of the year, being one for every 11.3 of population.

While such a large amount of work has been under way and such vast sums of money have been expended in the extension of the service, it is gratifying to note that engineers from other countries who have been devoting themselves to a study of the problems involved have agreed with the practice and plans of the so-called Bell companies in America and have adopted their methods.

Probably the most extended investigation of this nature ever made was that of the engineers of the British Post Office Department who, after months spent in study and travel in this and other countries, recommended as the basis of charge the payment for service by the message and, for small users, the payment for service at the time it is rendered, using coin receiving devices, or so-called slot machines, for that purpose. They also recommended for the rendering of the service the use of the relay multiple switchboard and trunk line switching machinery as designed and manufactured for the Bell companies in America.

While to the promoter, the manufacturer of apparatus and, especially, to the manipulator of securities, the extension of so-called " independent " telephone schemes has continued, in some localities, to seem attractive, there are many signs that the public is finding out, gradually, that these enterprises are designed for the immediate benefit of the few who are furthering them, rather than for the extended or lasting good of a community.

The Superintendent of the Department of Electricity for the City of Chicago has shown in a recent report on telephonic service and rates that in Cleveland, O., where the largest "independent" exchange has been in operation, the subscribers who have the telephones of both companies, could pay for those who have the opposition service only, the difference between their present rates and the highest rates charged for the same service by the Bell Company, and, by thus having all telephones connected with one exchange, secure all the benefits of their present service, be relieved from its disadvantages and save more than $400,000 per year.

The present apparent merits or demerits of two or more telephone systems in a city or town, versus one embracing all users, are questions which do not seem to call for extended consideration in looking broadly at the future of telephony. It will be difficult to controvert the conclusion that telephone service, as nearly as possible standard in its efficiency and cost, will be of the greatest good to the greatest number when rendered by means of one comprehensive system national, or even international, in extent. To provide for the requirements of such a system will be a task which will engage the best efforts of telephone engineers throughout the world. If anyone thinks the subject a limited one, let him consider that present accomplishments mark what were only a few years ago considered extreme possibilities.

In the item of cable construction, ten years ago conservative engineers recommended fifty pairs of wires as the greatest number advisable to be contained in one cable. To-day many cables are in use containing 400 pairs, or 800 wires. Less than eight years ago electric lamps were first used for signalling purposes on subscribers lines; to-day not less than 500,000 lamps are used for this purpose and light and flash many million times each day.

While the general lines of development seem now to be well-defined, the details necessarily involved in the performance of the service required, are almost unlimited in number and present to the engineering and executive forces involved problems of the greatest intricacy and interest. The introduction of the brilliant discovery of Dr. Pupin to general practice; the simplification of the apparatus used in every branch of operating work; the designing of trunk line plans and methods so that the greatest efficiency and economy may be accomplished; further development and improvement of plans for wire distribution; the designing of a satisfactory automatic message recorder, a simple and satisfactory composite or duplex telephone circuit and a practical telephone repeater; these are a few of the problems requiring the best efforts of our engineers

DISCUSSION.

PRESIDENT STEINMETZ:—Gentlemen, Members of the INSTITUTE and Guests: The topic of to-night's discussion is power transmission, but power transmission different from that which we have considered in previous meetings. It is telephony. It may be of interest, then, briefly to compare telephonic communication with long-distance transmission of large power, to see the similarity and the difference between them.

In telephony, as well as in long-distance transmission of large power, alternating currents are used exclusively. While, however, in long-distance transmission large powers of thousands of kilowatts pass through the circuit, the power of the telephonic transmission is exceedingly small, since the potential energy available in a pound of coal is sufficient to give an audible sound in a telephone receiver for millions of years, I do not remember how many.

In long-distance power transmission, from one or from a number of generating stations, power is transmitted through the circuit to one or a number of receiving stations. Thus, the stations are either generating or receiving stations, and the power flows over the circuit more or less continuously in one and the same direction. It is different, however, in telephonic communication. Here each one of a large number of stations is a generating station, as well as a receiving station in rapid succession—a generating station when speaking, a receiving station when listening. The problem here is to be able to transmit from any one of a large number of stations, power to, and receive power from, any one of a large number of stations. Hence, it is essential that the stations should be normally disconnected from each other and be able to be connected together in any desired manner, and here appears the necessity of the central station and the switchboard. I do not need to dwell upon this any further, since it will be taken up in the papers that are to be presented.

The most interesting characteristic feature and difference between telephonic transmission of speech and long-distance transmission of power, next to the difference in the magnitude of the power transmitted, is in the purpose of the transmission and thereby the character of the transmitted power. The problem of long-distance power transmission is to deliver as large a percentage as possible of the electrical power produced in the generating station at the receiving station; that is, to reach as high efficiency as possible; but the character of the power delivered is relatively immaterial, and therefore the simplest form is usually preferred, that is, a sine wave of current and electromotive force. The character of the wave shape, its distortion, is of more or less secondary importance, and frequently of no importance at all. Entirely different, however, is the problem in telephonic transmission of speech. The sound waves are very complex harmonic waves consisting of a fundamental and many higher harmonics or overtones, which by their frequency and their relative intensity give the character and distinctive difference between the various sounds, as the vowels and consonants, and thereby articulation and intelligibility of speech. It is the overtones which give the difference between the notes of the different musical instruments, etc. In telephonic transmission the sound waves are transformed in the generator, the microphone sender, into waves of alternating current, which are re-transformed into sound waves in the receiving telephone. As you see, the problem of telephonic power transmission, then, consists not in delivering a large percentage of the generated power at the receiving end, but in delivering at the receiving end power as nearly as possible of the same character, that is, of the same wave shape, as produced at the generating station. The problem, therefore, is the maintenance of the wave shape of the higher harmonics of the generated wave and not the efficiency of transmission. The efficiency of telephonic transmission is necessarily extremely small. Of the power supplied from the battery to the microphone circuit, probably an insignificant part of 1% is delivered as mechanical power by the diaphragm of the receiving telephone, but this is of no moment since the absolute value of the power under consideration is very small.

The capacity, etc., of the telephonic line tends to modify the wave shape and to suppress the higher harmonics; to discriminate against the higher harmonics which give the distinction between the different sounds, that is, the articulation and intelligibility of speech. Therefore, with the increasing length of the telephone line, gradually the higher harmonics decrease, articulation becomes at first impaired and then destroyed, and speech becomes unintelligible, not because power does not reach the receiving telephone in sufficient quantity to give a sound, but because the power reaches it at a wave shape different from that generated at the sending end, with the higher harmonics more or less suppressed. While in a long-distance power transmission, by increasing the impressed voltage, the transmission may always be improved, or made possible (within certain limits), no increase of power supply can make an inoperative telephone circuit operative, since the relative proportion of the components of the arriving wave does not vary with the power (except in so far as the operation of the sending apparatus may be affected by the power supplied thereto). Here, then, is a distinctive difference between telephonic and power transmission. This condition is made worse by the character of the telephone generator. By varying the resistance of the microphone contact in the circuit of the battery current, the current is made pulsating. Its pulsating component is transformed into a higher voltage alternating current, which passes into the telephone line. This telephonic generator tends more or less completely toward constant current regulation. The capacity of the telephone line absorbs a part of the current, proportional to electromotive force and frequency, that is, a larger part of the current of higher than of lower frequency, leaving, therefore, for reception at the receiving telephone, a lesser percentage of the generated current, the higher the frequency of the current is. This means the higher the capacity of the line, the less current of higher frequency reaches the receiving telephone, until speech becomes impossible. It is this discriminating character of the telephone line which causes the difficulty of long-distance telephony.

At the same time, this explains the characteristic feature of self-induction in the telephone circuit, and the difference between its action in telephony and in long-distance power transmission. Self-induction induces a voltage proportional to the current and the frequency. While capacity is discriminating against higher frequency, self-induction discriminates in favor of high frequencies, in constant current circuits, its electromotive force being proportional to the frequency. Therefore, in a constant current circuit the self-induction requires or causes to be generated an electromotive force proportional to the frequency of the harmonics. That means, in other words, in a telephonic circuit supplied by approximately constant current self-induction intensifies the higher harmonics generated by the sending apparatus, in proportion to the frequency, and thereby reduces the result of the diminishing effect of the line capacity on the higher harmonics, and the impairment of articulation produced thereby.

Heretofore all practical work in extending the distance of telephonic transmission has been done in trying to reduce the inherent discriminating effect of the line against higher harmonics or higher frequencies by reducing the line capacity as far as possible, so as to absorb the least possible amount of current, and by reducing the line resistance as far as possible so that as large a percentage as possible of the generated current may reach the receiving telephone. Probably the practical limit of long-distance transmission has been reached, or, at least, more or less closely approached; and further improvements should, therefore, be looked for only by inserting apparatus discriminating in favor of higher harmonics, as self-induction, etc. With distributed line capacity, self-induction, to discriminate in favor of higher frequencies and thereby reduce the objectionable effect of the line capacities, will have to be distributed also.

I do not need to dwell upon this matter any further, since it has been discussed in previous papers recorded in our TRANSACTIONS. However, the limit has by no means been reached and a very great amount of work will still have to be done, and may be done in this direction of inserting appliances to discriminate in favor of higher frequencies, thereby reducing the wave shape destruction due to the line capacity, and improving articulation and intelligibility of speech, that is, extending the distance of successful telephone transmission. Practically nothing has been done yet to make sending and receiving apparatus selective and discriminating in favor of higher frequencies, since the preliminary work done in this direction in the early days of telephony, by such investigators as Eickemeyer and others.

That brings me to the last point of which I desire to speak, and that is the telephonic relay. Thus far no success has been had with telephone relays. At the same time, it appears to me that the question of relaying telephonic currents has mostly been approached with a misunderstanding of the problem. It is not the problem to insert power into the telephone system to increase the power of the telephonic current, because we can get any power we want by increasing the voltage; the problem is to avoid the destruction of the wave shape. The telephonic relay, therefore, should insert power in such a manner as to be proportionate to the frequency, that is, discriminating in its power supply in favor of high frequency, otherwise no advantage can result over direct telephonic transmission in articulation and intelligibility. Nothing, as far as I know, has been done in this direction, although it appears to me that the problem is by no means hopeless, and I can see a number of directions in which it might be approached, although the difficulties are formidable, owing to the high frequency of the currents under consideration.

I desired to dwell upon the engineering feature of telephonic communication somewhat more fully, since the papers scheduled for to-night do not consider the subject from this point of view. I now call upon Mr. Arthur Vaughn Abbott for the first paper.

The papers of Mr. Abbott and Mr. Dommerque were then presented.

MR. J. J. CARTY:—Mr. President and Gentlemen: I think the INSTITUTE is to be congratulated on having such an efficient Committee on Papers, because for the first time in the history of the INSTITUTE we have had a telephone meeting. I am glad to see, even at this very late day, that the INSTITUTE evinces an interest in telephony and recognizes in this formal way that there is such a branch of electrical engineering as telephone engineering, and I think we are fortunate in having to-night two papers from such distinguished telephone engineers as Mr. Abbott and Mr. Dommerque.

I remember what a hard time the telephone companies have had in interesting the public in the fact that there is something to the telephone besides that which subscribers see on the wall in their offices and something besides that through which they sometimes hear in the instruments in their offices. Mr. Abbott very well brings out the fact that the telephone engineering features are brought to the mind of the subscriber principally from viewing an instrument, costing an insignificant sum, attached to the wall, and that subscriber, even though he may be an engineer, is apt to get the idea that that is the beginning and the end of telephony.

It being my habit each year to add to my staff some graduates from the various technical schools, my talk with them reveals the fact that it is often the case that when they have grasped the principles of the Bell receiver and know the effect of variations of pressure upon certain conductors of high resistance, their idea seems to be that they have mastered those questions which relate to telephony; that a few weeks and one or two lectures on that subject are enough, and then all of their time is devoted to those engineering questions which involve large units, horse power, and so on; and I am glad to find that attention is called to the fact that there is a branch of electrical engineering which relates from the telephone. These two papers to-night have touched upon that subject.

I feel greatly indebted to the Committee on Papers also for the opportunity I have had of listening to the excellent remarks which our President has made on the subject of the analogy between long-distance transmission of power and the transmission of speech, and, what is more important, the difference that he pointed out between the two. I think I could dissent from the first of what he had to say. I would suggest that possibly the statement that the telephone generator, that is, the transmitter, is a constant current instrument, might possibly be made a little more accurate. I say this, subject to correction later, having in mind that the telephone circuit is never a constant current circuit, that we must always take the capacity into consideration, and that as we add to the capacity we increase the current output to the generator. That factor if neglected might lead to discordant results sometimes.

Coming to the papers proper, I think the author of the first paper, in paying a high tribute to the mathematical attainments of the President, has understated the case; but I think that he was governed somewhat by undue modesty when he went further and deprecated the fact that the telephone companies had not had the services of mathematical scholars of a high degree of ability, because we should all remember that Mr. Abbott himself, with whose mathematical attainments we are all familiar, was for a number of years in the employ of a licensee of the Bell Telephone Company, and I am sure that during that time that company had the benefit of his best efforts.

I think that this is not the time, neither is it the place, to discuss the propriety of the business policy of any of our electrical concerns. I will not undertake to dwell upon that phase of the subject, but when there is brought up here the question of the liberty of speech, I think it best to say a word. It is interesting to find, if the author of the paper is to be followed in this matter, that the developments of the electric light, the electric railway, etc., which have taken place in this country, have been in consequence of our freedom of speech. I do not assent to that doctrine; neither do I dissent from it. That is a pretty philosophical question. It might well form the theme for discussion at a meeting of the Metaphysical Society; but I think that a fact or two at a time like this is not out of place, and I will present one touching the matter of the freedom of speech. I have no doubt that the author of the paper has been told that good telephonists should be seen and not heard. That may have been the experience of one man, but " One swallow does not make a summer," and we cannot reason from one particular case to general conclusions. So far as I am personally concerned, I have always enjoyed complete freedom of speech regarding telephone matters as well as all other matters. I have at times asked advice of my superiors as to whether certain publications would be advisable, and I have always received an answer to this effect: " You are the best judge, you know the circumstances of the case, and it rests with you to say how much you shall publish and how much you shall not publish." It is always an interesting question of ethics—it is an interesting one for the engineer particularly—to determine to what extent the data which engineers have gathered following the work of their employers, are the property of the engineers.

I think Mr. Abbott has done a very great service in calling attention to the fact that there is such a thing in telephone work as maintenance. As I said before, in a consideration such as this, a few facts are always of interest, and, in the best of good feeling and without in any way wishing to antagonize the author of the paper, but rather to bring out in a friendly way points for discussion, I call attention to one statement which I think requires a few words.

" The manufacture of apparatus, particularly of transmitters and receivers, was sedulously guarded, and the magneto bell, the receiver and solid-back transmitter stand to-day, after one and two decades of experience, unchanged and unimproved."

First, granting that this is true, does that indicate a lack of efficiency? Certainly not. Are we to judge of the efficiency of engineers by the size of their junk heap, or rather should they not be congratulated when out of a world of junk they can produce at least three pieces of apparatus which can persist for a number of years. I think there is not much doubt on that point. But, unfortunately, telephone engineers are not allowed to claim that credit. Whether for good or for ill, the facts are contrary to those stated in the paper. Let us consider the case in New York. Take first the case of the magneto bell, with which I am particularly familiar. Prior to 1889 the history of the magneto bell was the history of the junk shop, one group of bells following the other in quick succession into the waste pile. Was there to be no end of this? It fell to my lot to design a bell which I described with some publicity at a telephone meeting. Prior to that time no telephone company had used such a bell, After that meeting all of the telephone men went home and began discarding the bells of that date and putting in one which I described, and it has since become known as the " bridging " bell and has attained some prominence. Incidentally I will state that that prominence has been brought about by a controversy over a metaphysical question; the question being this: Was the thing which Mr. Carty did an invention, or was it engineering—the question as to whether I did it not being in dispute. That bell, whether it was an invention, or whether it was engineering, went into general use. Is it any less to one's credit that it has persisted and been kept in use ever since? I think not. But, unfortunately, I am not allowed to take that position, because after the announcement of the—I was going to say invention—production of that bell, all of the magneto bells in the City of New York and in all the larger cities were discarded and this new type was installed. There were large additions to the junk heap then. Those bells continued in use up to four years ago; then, owing to progress in telephone matters, it was decided by my company to discard all those bells and to replace them by others using the bridging principle, but not the magneto, because they were to be used in connection with the common battery system.

That is such a striking contradiction, I may say, of the language of the paper that it would be grossly misleading if I did not call attention to it. Four years ago there were 30,000 or 40,000 of those bells in use in New York, all of which have been discarded and replaced since. So that as far as the magneto bells are concerned, the type has persisted, but the use of those particular bells has ceased.

Now, respecting the telephone receiver, that has been regarded as one instrument which was well-designed and which answered its purpose admirably. I think no mistake was made in so regarding it. Therefore, instead of it being an example of lack of progress, it is an example of an excellent design which should be commended. But even in that respect we are not allowed to take too much satisfaction, because in the last five or six years we have taken out all the receivers we had in use and sent them to the junk heap. That does not look like stagnation. But that is not enough. Of the new crop there has been type after type, one following on top of the other, at the cost of enormous sums of money. So that when we come to examine even the question of the receiver we find that although the " manufacture was sedulously guarded " it is not the same that we have used for the last one or two decades.

Now we come to another feature, the solid-back transmitter. A number of years ago the British Government instituted a series of tests of all the transmitters in the world, and the result was that the solid-back, or American type, was not adopted. I was greatly surprised and I spoke to Sir William Preece on the subject. I found that in making the tests he had not been advised that a special induction coil was needed to fit the solid-back transmitter, and that he was not advised that a certain amount of current, which could only be practically obtained from the Fuller battery or some equivalent type, was needed for its operation, and that he made the test with gravity batteries, giving a low volume of current and with a type of coil not suited to the transmitter, so that his tests were rendered less valuable on that account. Other tests were made—one, I think, by the Swiss Government—the result of which was to choose the American type of solid-back transmitter. The fact is to-day that notwithstanding all the work that has been done in England by the English Government, in France by the French Government and by others, the transmitter here referred to has been regarded as the best or equal to the best. But even good as it was, that type has not persisted because within the last four years right here in New York we have removed 50,000 telephone transmitters of that type and replaced them by a modified type. So that in these three instances, which apparently would indicate that progress had ceased, we find that the facts show that improvement has gone on as before.

There is one more point about which I would like to speak, and that is the analogy between talking over the telephone and "buggy riding." It is said that when we hire a rig at a livery stable we have to pay in accordance not only with the character of the outfit, but in accordance with the time which we use it. If we ever attain a period of ultimate justice, which not even the most eminent mathematician could attain, such an arrangement might apply to the telephone business; but I think that while we are discussing analogies it might be well to consider this: Think of the injustice which is done to the man who gets into a street car at Bowling Green and rides to Wall street, when another man may get into that same car at Bowling Green and ride to Harlem. Now, when the tariff on the street railways is so adjusted that the mile ride is the basis of the fare, then such an arrangement may be possible in a talk over a similar territory. Again, it might be said that a two-cent stamp will carry a letter from Eastport, Me., to San Francisco. Think of the unfairness and injustice involved, then, in charging two cents for sending a letter from Eastport to Portland in the same State. I merely mentioned the other simile in order that those who wished to consider the question of telephone rates might have that in mind, not to confuse them, but to aid them.

I once had the privilege of being called in consultation with a most distinguished professor of political economy on the subject of telephone rates. This professor was called in on account of his wisdom and knowledge of such matters. He had previously distinguished himself in the matter of railroad rates and he has since become the president of one of the largest universities in America. After going over the whole subject as well as he might at a conference, he is reported to have said that he found that the railroad rates were very easy, but that the question of telephone rates was beyond him.

Now, my idea in bringing up these matters with reference to rates was not to oppose what has been said to-night, but rather to place alongside of those considerations certain other considerations and merely to emphasize what the author of the paper has so well said, that in these directions lie engineering and economic questions of the greatest importance, not to be settled in a moment and not to be settled merely by argument, but by resort to facts and the fullest possible consideration.

MR. EDWARD P. THOMPSON:—I would like to say in reference to what Mr. Carty has said this evening that I wish that he would touch upon the progress made in connection with the use of dynamos for telephone circuits. I am particularly anxious to know what has been done practically in that line, and possibly there may be others who would also like a little information on that point. I mean, of course, the current which goes through the transmitter and the telephone circuit.

MR. ABBOTT:—Without endeavoring to create a discussion, because that is the very last thing I want to do, I should like to make one or two comparisons as well. We have just heard a most excellent speech from Mr. Carty, and we know he is a good author, because we had a paper from him some years ago which has been really a monument in both the electrical and the telephonic world. Why has he never written us another paper? Personally, I have learned a great deal from Mr. Carty, and I am sure I could learn a great deal more from him, and I wish he would give me another chance.

With regard to the receiver and the transmitter, it is probable that in the paper I was not explicit enough. I should have recollected my engineering training rather than my economic training and should have gone into details and specifications. To what extent have the changes that Mr. Carty has alluded to actually improved the efficiency of signaling and transmitting? To what extent to-day can we signal more surely or better than we did ten years ago? Will the magneto bells to-day ring better, will they ring louder and more surely so far as the bell is concerned? We will eliminate the question of the power generator at the switchboard, which has been improved; we will eliminate the question of the switchboard apparatus. But to what extent has the ability of the operator at the central office to send a signal, and of the subscriber at the sub-station to receive one, been enhanced by the changes Mr. Carty describes? In a similar manner, to what extent have we improved transmission by changes in the transmitter since the original White solid-back? It is very true that in almost all the cities we have substituted what is called a common battery receiver and transmitter for the older forms of high resistance receiver and low resistance transmitter. But has transmission been improved? I think not, to any very marked extent. On the contrary, if I may transcend the professional ethics of which Mr. Carty spoke a few moments ago, and if my memory serves me correctly, the average transmission of the common battery receiver and transmitter is about 80% of that of the local transmitter and receiver when in its best condition. It is true, as Mr. Carty will probably point out in a moment, that the local battery was not of such a nature as to give constantly 100% transmission, and in that respect and to that extent, transmission has been improved by the substitution to which I think Mr. Carty alludes.

Analogies, like averages, are dangerous. There is no question about that, and I think Mr. Carty uses some which are open to correction. I did not attempt to remodel the ethics of the street car companies nor to correct the abuses of the post office. That they exist is unquestioned. That perhaps the telephone tariffs are no worse, may be true. That, to my mind, was not the subject under discussion, but it was the question of the correction of a particular thing that seemed to need it. Undoubtedly, Mr. Carty could suggest a method which would improve both the post office and the street car service.

MR. CARTY:—A member who spoke just before Mr. Abbott asked in regard to the use of dynamos in connection with the telephone. While that is not immediately concerned in this discussion, I have no objection to saying a few words in answer to him. I presume the question is, how far a dynamo might be used for serving for a number of transmitters at once. That is a matter which occupied a great deal of attention some years ago, and, before that the question of how a number of telephones might be used from one battery was considered; and, while it may now seem strange, yet the fact is that a number of men, then learned in the art, had attempted to use two or more telephones from one source of battery current, and they were met always with this difficulty: When one was talking anybody who had a transmitter supplied by the same current could hear the talk, whether it was intended for him or not. It may seem easy now to those who have all of the facts before them to account for those troubles, but the fact is that many years intervened before we knew what was the trouble. I believe the first time that two or more telephones were run from one battery was an experiment which I made in the Western Electric Company in 1887, when I appreciated the fact that we needed a low internal resistance battery and consequently a constant potential source of supply. It is well enough to talk of constant potential in reference to electric lights when we are dealing with the eye; when we have the retina, the active part of the eye, which will not respond promptly to changes in illuminating power, and furthermore, when we have an electric lamp which will not respond readily to changes in current. When we come to talk of constant potential in telephony, it becomes a question of almost mathematical precision; and, to my surprise, I found that a large number of telephones connected to a few cells in parallel could be used as a supply for a number of telephones operated simultaneously. That was the first practical common battery system ever to be employed. Storage batteries at that time were not so reliable as they are now, and there was a very natural desire to replace the battery by unipolar machines, which had been suggested, and some work was done in that way. Nothing has come of that, and to-day as a rule dynamos are used for supplying telephone current for operating transmitters only when the dynamos are bridged by suitable storage batteries, in order, as it were, to smooth out the current and to supply suitable e.m.f., when the commutator is at certain points. Some experiments have been made with special machines with a view to doing away with the storage batteries, but not much has come of it. The gain is not great. I think this will probably answer the member's question.

MR. H. G. STOTT:—I would like to ask another question which I am sure the telephone people think is a very interesting one, and that is, as to the developments which have been made in following out the theorems originally propounded by Oliver Heaviside sixteen years ago, and more recently revived by Dr. Pupin, as to the attenuation of wave form, and so forth, and the means of remedying it. In attempting to read Heaviside's papers, I remember one sentence in particular where he concluded a long series of mathematical demonstrations by saying that "self-induction was the life and soul of telephony." In looking over Dr. Pupin's papers more recently, it seems to me that the whole general subject was threshed out very fully by Heaviside, but I would like very much to hear what progress has been made in following up Dr. Pupin's more practical work.

MR. CARTY:—I regret very much that Dr. Pupin is not here himself. His work, I am proud to say, was the basis of a most important telephone paper, and I think was not recognized as such at the time; but now that we are counting noses on papers I would like to have that mentioned among the telephone papers.

I do not undertake to speak with any authority on the subject of Heaviside or of Dr. Pupin, but I will put my remarks in the form of questions and not in the form of assertions, and in reply to the remarks of the gentlemen, I will ask:

Is it not true that Oliver Heaviside called attention to the importance of introducing into telephone lines self-induction under certain circumstances?

Is it not true that others, as well as the speaker, read Oliver Heaviside's papers years ago and since?

Is it not true that others, following as best they could, the instructions of Oliver Heaviside placed self-induction in the line?

Is it not true that others, having followed and having been guided by Heaviside, failed to produce the result which Heaviside thought should be produced?

Is it not true that Heaviside himself in his works said that he must confess that practical trials had not borne out his expectations?

Is it not true that Dr. Pupin has come along and told us that this self-induction is a good thing to put into the telephone line, if you put it in in a certain way; that self-induction is a bad thing to put into the telephone line if you put it in in another way? In what way should this self-induction be inserted into the line? And, if I recollect right, is it not true that Dr. Pupin said to put the self-induction into the line in certain definite amounts as he stated, placed in the line with special reference to the wave length?

Is it not also true that he showed us how to determine what the wave length is, and has he not told us which condition we should regard the wave length as representing; that is, whether it represents the line when it has self-induction in it, or before?

I put this in the form of a question, as to whether Dr. Pupin has not told us precisely how to put self-induction into the line, in precisely what relation to the wave length, and told us, as well, precisely how to calculate the wave length. I think that a proper pondering upon those questions might reconcile the difficulty which is in the mind of the questioner, and I know of nobody better able to answer these questions that I have put, than our distinguished President.

PRESIDENT STEINMETZ:—Gentlemen, I suppose I shall have to answer, as you seem to wish to have me do so, and I will try to do it. What Heaviside has done is to show how distributed self-induction inserted in a telephone line improves telephonic transmission by eliminating, as I stated in my introductory remarks, the destructive effect on the wave shape of the line capacity. The line capacity being uniformly distributed along the line, it follows that self-induction must be distributed uniformly along the line. Very considerable self-induction is required, however—too much to make it practicable to insert it uniformly in the line. Trials have been made, then, to insert self-induction locally in the line, either at one end or the other, or at a number of places. The results were discouraging: Where, without self-induction you could hear a little, with the self-induction you could not hear at all.

I do not care to go into the mathematics of the problem, but will try to illustrate the cause roughly on the blackboard.

Let us follow the telephone line from the receiving telephone toward the sending end. At the receiving end a certain current is required to operate the telephone. Following along the line, from mile to mile, to this telephone current—which is slightly lagging—adds itself the current consumed by the line capacity, which is leading 90°. The line current thus becomes leading, first slightly, then more and more. As long as the lead is small, the current is not much increased, since the energy current flowing into the telephone, and the 90° leading current of the line capacity combine to the resultant current as the hypothenuse of a right triangle with the two component currents as sides. With the increase of lead, however, to 80°, 85°, the resultant current increases greatly, and thereby the energy consumed in the line, and this effect is proportional to the frequency, so that ultimately only an insignificant part of the generated high frequency current reaches the receiving telephone.

Prof. Pupin has shown as the result of mathematical and experimental investigations recorded in our TRANSACTIONS, that self-induction, to be beneficial in a telephone line, must be inserted at so frequent intervals, that before the current has reached a considerable lead, that is, before it has noticeably increased, it is changed by passing through the self-induction, to a moderately lagging current, then along the line gradually becomes leading again, but before noticeably increasing, passes the next self-induction, etc. That is, Dr. Pupin has found that the limiting distance, in which the reactive coils must be inserted, must be such that in this distance, for the highest frequency of importance in telephony, the current does not assume such a lead as to increase seriously. If this condition is fulfilled, the current all along the line is approximately a minimum, that is, the energy consumption or attenuation of the power is a minimum.

If, however, self-induction is inserted in wide intervals, as in all previous experiments, while the current has already reached an excessive lead, the only effect is to change the excessive lead to excessive lag. This gradually diminishes and again changes to excessive lead, is at the next reactive coil changed to excessive lag again, etc., but the resultant value of the line current is still just as excessive, whether lead or lag, and the attenuation or loss of energy, therefore, such as to destroy speech. No benefit is therefore derived from the self-induction in this case in reducing the resultant current in the line, except for very low frequencies which may be benefited. This, however, means a discrimination against higher frequencies, or the very thing which is objectionable in telephony, in destroying articulation. This feature, together with the increase of the effective length of line caused by the insertion of a few large reactive coils, is the cause of their harmful effect, observed in previous experiments.

MR. STOTT:—I think Mr. Carty very nicely side-tracked my question, as to what had been accomplished in the way of progress in using Dr. Pupin's system.

PRESIDENT STEINMETZ:—I may say regarding thereto that I am not very familiar with the practical application of the invention, but I do not doubt that the invention is extremely useful. You must consider, however, that some years must always elapse between invention and practical application. It was in the 90's only that the first induction motor was developed, a number of years after its invention. It takes a great deal of time to develop things. You must consider that induction coils have to be designed to give the most effective inductive effect with the least energy consumption. If you consider that the frequencies that you have to deal with probably reach 3,000 or even higher, you see that this by itself is quite an engineering problem, to develop such induction coils suitable for being strung along a long-distance telephone line every few miles or so. I am sorry that Dr. Pupin is not here to tell us more about his work in this direction.

MR. THOMPSON:—I would like to mention some experiments which I made. I had occasion to test various transmitters, and made some investigations of the powers of different substances. One interesting result was that they seemed to show that it was possible to make a metallic telephone transmitter on the style of the carbon transmitter and yet without producing pressure of the electrodes. That, you may remember, was quite a problem once—to produce a variation of current without compressing the high resistance conductor. Regarding the result, the telephone effect is as loud as if a magnetic telephone were used, but it is not as loud as with a carbon transmitter. Without taking time for details, I will mention only the principle underlying the mechanical construction, which consists in bringing the particles of metal into more intimate contact by a suitable force independent of mechanical pressure, care being taken to avoid compressing the granules between the electrodes. I so constructed a device that the force of independent electric energy directed upon the transmitter could be employed, and in such a manner that when the device was exposed to air vibrations, this electric energy, instead of the pressure, was varied. The particles were metallic and so were the electrodes. Reiss had a hard time in trying to prove that his telephone was operative for articulate transmission, although made of metallic electrodes,and that was the foundation of Berliner's first patent, as you know. It has generally been accepted that we cannot make a transmitter by using metal. Half a word is transmitted, for example, and then the current is broken and the other half is missing. Metal will act as a microphone, more properly speaking. Take a watch and put it in contact with a sounding board, and put a metallic microphone on it, and it will act as a transmitter, but just as soon as air gets in between the original sound and the microphone, we will find it impossible to catch full words in the receiving telephone.

Another experiment showed me that when a magnet was brought near a diaphragm of any microphone transmitter, the sound became fully twice as loud in the receiver. It is almost impossible to get a transmitter in the best adjustment, but with a magnet that adjustment may be made better than by any mechanical process. If the magnet is brought on one side of the diaphragm, it may strengthen it and bring the adjustment right; that is, it will strengthen the microphonic power by putting it on a certain side, and weaken it when put on the other.

It occurred to me to try the lodestone as a substance possibly having microphonic property even greater than that of carbon. By taking a piece of lodestone and bringing an iron point down and pressing upon it, the galvanometer needle will indicate the increase of current to a much greater extent than with carbon. Lodestone, however, would not be as suitable as carbon for a transmitter, because of the difficulty in manufacturing it into any suitable shape, being so brittle. At the same time, it has the property of microphonic variation to a much greater extent than carbon, although carbon has heretofore been considered, I think, to have the property much more than any other substance. Of course, all substances of high resistance have that power, more or less.

MR. W. J. HAMMER:—The President in his admirable opening remarks stated in substance that up to the present time no telephone relay had ever been made to work. I may perhaps be pardoned for calling attention to some experiments which I made 13 years ago in which a telephone relay actually did work successfully. Through the courtesy of the American Telephone and Telegraph Company of New York, which in 1889 extended to me the facilities of its lines from New York to Philadelphia, some interesting experiments were made where a telephone relay was in actual operation. On Feb. 4, 1889, I had the honor of delivering a lecture upon "Edison and his Inventions," before the Franklin Institute, and took three of Mr. Edison's remarkable inventions, namely, the loud-speaking telephone or electro-motograph receiver, his carbon telephone transmitter, and his phonograph, and worked them in juxtaposition, they constituting an operative telephone relay. At the New York end of the line there were stationed at 18 Cortlandt street, speakers and musicians, who spoke, sang and played in front of the phonograph. The phonograph was then placed in front of the carbon telephone transmitter, at 18 Cortlandt street, and the speaking, singing and cornet playing were transmitted to Philadelphia and there repeated by the loud-speaking telephone receiver, and every person in the Franklin Institute heard music. Those who have experimented with Mr. Edison's loud-speaking telephone receiver know that an audience of 5,000 persons can hear it.

At Philadelphia there was a second Edison phonograph which recorded the talking and music coming from the receiver. This second phonograph was then placed in front of a carbon transmitter and the singing and music and talking were sent over a local circuit around Philadelphia and back to the stage of the Franklin Institute. There it was reproduced to the audience by a second loud-speaking electro-motograph receiver.

In that particular experiment, therefore, there were employed two Edison carbon transmitting telephones, two Edison motograph receivers or loud-speaking telephones, two sets of induction coils and batteries, and 104 miles of long-distance metallic telephone circuit, 6 miles of which was underground and sub-marine cable, and 98 miles of which was wire strung on poles. Those who were present at the Franklin Institute on the night of Feb. 4, 1889, will confirm the statement that the apparatus shown constituted an operative telephone relay.

In subsequent experiments that I have made on the other side of the water, in Paris at the Exposition of 1889, and on other occasions, where I repeated those experiments, they were likewise successful. I know that Lieut. Jarvis Patten and others, who have spent a great deal of time and money on telephone relay work, have stated that the only telephone relay which actually operated as a result of an enormous expenditure of money, time, etc., was the telephone relay that worked on the occasion referred to. I felt that, in view of the President's statement, it should be mentioned that there was at least one telephone relay that had actually worked.

MR. CARTY:—I wish to have the privilege of moving a vote of thanks for the very interesting papers read by Mr. Abbott and Mr. Dommerque, calling attention to the fact that in the question of telephone rates there is an engineering side.

MR. ABBOTT:—I would suggest, Mr. President, that the motion should include Mr. Carty, for I think he has contributed as much, and perhaps more than the others, to the pleasure of the evening.

PRESIDENT STEINMETZ:—The Chair takes pleasure in putting the motion, with the amendment suggested.

The motion was carried, and the meeting on motion adjourned.

DISCUSSION AT CHICAGO, MARCH 28TH, 1902.

Mr. R. H. Pierce in the Chair.

MR. F. J. DOMMERQUE:—It is certainly astonishing what a progressive movement the telephone has made in the last few years. During the first eighteen or twenty years of the régime of the Bell telephone company, the expansion of the telephone business was very limited. For instance, in Chicago in 1899 there were not more than 22,000 subscribers. At present the number is double that. The same is true of most cities all over the country, except where there is an independent plant. Why should this movement of increase in numbers of telephones have taken place just in the last few years? Personally I can see no other reason than that the Bell company, during the period when no competitor was in the field, knew that it was cheaper and netted them more revenue, if they had a limited number of subscribers and charged a high rate, than to charge a low rate and have a large number of subscribers, for with a large number of subscribers there is a good deal more labor and expense which has to be paid for. With the appearance of the independent company in the field, the Bell company, it seems to me, has had to change its policy by reducing the rates and obtaining more subscribers. A great deal is due to the independent movement for such a large increase in the number of subscribers, I am sure. It may be that Mr. Hibbard does not feel the way I do, but I thought it was well at least to call attention to this fact.

With reference to Mr. Abbott's paper. I would like to call attention to a few points: On the third page, after the introduction, the author states: "It is possible to-day for anyone to build a first-class telephone exchange, and with good care, shrewd and expert management, to give service that cannot be excelled, at the lowest possible price. Such, I say, is possible, but, unfortunately, it is rarely done. On the contrary, a very erroneous idea prevails in the mind of most of the independent companies as to the requirements and limitations of telephony," etc.

According to this statement, I judge that he means that all they do, in the independent work, is to put up a stick, tie a line to it, and the work is all done and they have a telephone.

I want to call attention to Table II., General Telephone Statistics. At the bottom of that page Mr. Abbott says: "This table is compiled from various sources, and is believed to be fairly accurate within about six months." Furthermore, he says that "B" and "I" signify "Bell" and "Independent" plants respectively. The first city mentioned is Baltimore, where the Bell people have 6,300 telephones and the independent company 6,000. You will observe they are pretty close together in the number of telephones, and I think the independent company did well to get that many where the Bell company had been operating twenty years.

The next city mentioned where the two companies are operating is Cleveland, where the Bell company has 13,744 subscribers and the independent company has 9,000. Again the independent company has a pretty good showing.

This table shows that in Columbus the Bell company only is operating, but as a matter of fact, there is an independent company there also, which has a good many subscribers. The same is true of Indianapolis. There is also an independent company in Pittsburgh with a great many subscribers; also in St. Louis and Minneapolis. Coming back to where the comparison is given between the Bell and independent companies in Cleveland, the Bell company is recorded as having 13,744 subscribers against 9,000 for the independent company. That means 50% more. When you look at the next columns you will notice that the Bell company uses 83,484 wire miles to connect 50% more subscribers than the independent has. The independent company uses 27,000 wire miles, and therefore the Bell company needs three times as many wire miles to connect 50% more subscribers than the independent. You will notice that the Bell company needs 3.2 wire miles to connect, per subscriber, while the independent people need only 1.4.

We will make another comparison. In Rochester, the Bell company has 4,200 telephones in use and the independent company has an equal number. The number of wire miles per subscriber for the Bell company is 3; independent, 1.25. This is not quite three times as much. The independent companies give continuous service in Cleveland and in Rochester at lower rates than the Bell licensees, which is justified, as the independent engineers build their plants more economically than do the Bell engineers, as proved above.

Then again the author says: "Half-a-dozen of the prominent citizens of some town conceive the idea of a telephone exchange, an ordinance is rushed through the City Council, of which one or more of the ' prominent citizens ' are members, a company is formed; enough stock subscription is raised to pay current office expenses and the labor of erecting a few miles of wire." etc., etc. He continues and at the end says: " Indeed, the preliminary puff is already felt, as is testified by the present lamentable financial condition in Cleveland, for if ever the true epitaph is written over the unfortunate Everett-Moore syndicate it will read, " Died of too much telephone." Why cannot the syndicate see its way clear to part with the telephone holdings, for which there are plenty of bidders? Because the telephone properties are good dividend payers. It was the street railways that caused all the trouble.

On page 382 the author says, "The independent companies are weak in their lack of coherence, feeble in possessing but few exchanges in the larger towns, and almost none in the great cities, and powerless in the toll and long-distance field." Of course, the statement that the independent companies are powerless in the toll and long-distance field is very true, and when the independent people have the toll and long-distance connections, which they will have, then the competition with the Bell company will be very close. I have found that in all the cities where the independent people have started exchanges, the money invested in these exchanges has been put up mostly by the prominent citizens and the best merchants and bankers in those cities. In St. Louis a great deal of the money was invested by the prominent brewers. They are the largest shareholders of the independent company there, and it stands to reason that those men will look out that the money which they have invested in their own city is taken care of. The principal shares of the Bell telephone company in all the prominent cities in the United States are owned by the Boston interests. It is a very hard thing to fight against the local company, if the prominent local people are interested in the independent movement.

As far as investment is concerned, of course at the beginning of the independent movement there was a good deal of speculation, as Mr. Abbott states in his paper very correctly, and to a great extent there is speculation still, but it is only an exception at the present day if the independent movement is not worked upon a proper and sound financial basis. The independent engineers have made many mistakes, but they have shown that they know enough to construct a plant for less money than the Bell company, and the plants give good service; if they did not give good service, the subscribers would not patronize them.

There is a table on page 384 which gives the probable installation cost per station of a telephone plant sufficient to serve 15% of the population. Just preceding this table there is this statement: " It is possible, even in such a city as New York, to install a telephone plant at a cost not to exceed $60 per substation." That price seems very low. The price of substation apparatus is given as $15. Now, a telephone for common battery service ought not to cost more than $9 or $10, and installation $2, making $12. The cost of wire plants (subscribers' and trunk lines) is $21 a subscriber. I cannot very well believe that this is possible in a large city like New York. Furthermore, the author says that the cost of switchboard apparatus for subscribers' and trunk lines is $12.11 and $6 respectively. If we were not to get more than this, we switchboard manufacturers would go out of business, so I think the total charge of $54 is very low, and I think the independent company would not undertake the work at that price in New York; I believe that Mr. Abbott's figures are high enough for small cities.

THE CHAIRMAN:—I notice that Mr. Abbott, in his paper, suggests that the method of charge be based on the number of messages and also on the length of time the subscriber is talking. He suggests the use of a meter, which he says would cost about $3, to record the number of connections and also the total time that the subscriber talks. I suppose he means during the month. I must say that I cannot see how this will give a fair record; that is, how the record would be an indication of the expense to the company of furnishing such service, even if there was a meter which could be installed for this purpose for that price. It would seem to me, offhand, that such a meter would very likely record more where poor service was furnished than where good service was furnished. I would like to hear an expression of opinion as to that from some one who is in the telephone business.

MR. DOMMERQUE:—As far as the cost of the meter is concerned, I think one may be produced for $3, but it seems to me that the whole principle of measuring service in the same way that it is measured in electric lighting, is wrong. In fact a comparison between telephone and electric light service is not the right one.

Those of you who have been in Europe and have traveled on the street cars on the Continent, know the difficulty of the street car system, where you pay according to the distance you are going. If you are going one mile you receive a red ticket; two miles a green ticket, etc. If you are going " through " you receive another ticket. In addition you have to save your ticket, as now and then an inspector will enter the car and will ask to see your ticket. This makes traveling very troublesome. The Continental companies are now introducing systems like those which we have here, and the people like the change, as it makes their traveling much less bothersome. On the elevated railroads here, you pay your nickel and are carried as far as you wish to go, whether one block or a dozen. You never complain if you are charged a nickel for riding one block, the same fare as one pays who rides a dozen blocks. The same thing, it seems to me, should hold true in connection with the telephone business. We want to do a great volume of business and the subscriber should be unobstructed and unlimited as to the number and duration of calls he makes. The idea of the use of a meter at the subscriber's station is not correct anyway, as such a meter would record every call made, regardless of whether the subscriber obtained the desired party or not, *i. e.*, all busy calls would be recorded and consequently paid for, if the meters were at the subscriber's station. Therefore, it is necessary that the meter should be at the exchange, so that it may be acted upon by the apparatus controlled by the calling subscriber as well as by the apparatus controlled by the subscriber called for. Anyone familiar with the use of such meters can tell a story about them.

ABSTRACT OF DISCUSSION AT MINNEAPOLIS, MINN., APRIL 7TH, 1902.

The Minnesota members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and other gentlemen interested, held a meeting in the Electrical Building at the University of Minnesota on April 7th to discuss the three INSTITUTE papers on Telephony. The discussion was participated in by nearly all of the nineteen present.

Among other points, attention was called to the fact that capacity effects were of much greater relative importance in telephony than in electric lighting or power transmission, electromagnetic induction having very little importance along the line. While the dominant fundamental tones of an ordinary man's voice range around " lower C," having about 132 vibrations per second, and therefore give a frequency comparable with those commonly used for electric lighting and power transmission, the overtones, which give character to the voice, have several times that frequency. Since the current or the quantity of electricity absorbed in electrostatically charging the parallel wires of a telephone or other transmission line is proportional to the frequency, it follows that the components of the current waves due to the high-frequency overtones are dissipated along the line much more rapidly than the lower frequency fundamental tones. This effect changes the character of the sound so that the average voice as heard over the telephone is quite different from that heard in immediate converse. This is one reason why it is frequently difficult to recognize a familiar voice over the line and why those who know each other only by communicating through the telephone, find quite different voices when they meet face to face. The blurring of sounds in long-distance telephony is due partly to the fact that certain sounds such as " s " and " e " are of very much higher pitch than others, such as " o " and " u," consequently they are obscured in many cases. When the consonants are inferred from the vowel sounds rather than from being heard, the obscuring of some vowels and the emphasizing of others makes it surprising that intelligent conversation can be carried on as far as is common. The apparent contradiction that the telephone girls with voices pitched higher can maintain communication intelligently over lines which give simply a confused roar for men's ears and voices, may be explained by the sharper ears and intuition of the girls, by their greater skill in articulating distinctly and by their care to avoid speaking at a pitch near the natural vibration of the transmitter diaphragm. The character of the voice is affected to a considerable extent in passing through the telephone repeating coils, the higher tones being muffled in this case by electromagnetic induction and by hysteresis. These changes in the character of the voice as reproduced in the telephone become very annoying when it is difficult to prove one's identity and give some justification for the frequent though vulgar preliminary demand: "Who is this?"

Note was made of the more liberal policy of the Bell interests in late years in connecting with independent exchanges on toll lines. In Iowa and probably in other States, interchange of traffic between rival exchanges is compulsory.

In the discussion of upkeep, stress was laid upon the necessity of distinguishing between depreciation and maintenance. Changes of route and of exchange methods amount to more than depreciation. Some copper wire put up several years ago which cost 11½ cents per pound, now sells as junk at 14½ cents. In some places cedar poles last only five years while generally they last ten to twelve years. Some poles erected in 1888 seem to be in good condition to-day.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 25th, 1902

The 164th meeting of the INSTITUTE was held this evening, President Charles P. Steinmetz in the Chair. The meeting was called to order at 8.25 P. M.

SECRETARY POPE:—At the meeting of the Board of Directors held this afternoon the following associates were elected:

NAME.	ADDRESS.	ENDORSED BY
ANDERSON, EDWARD H.,	Designing Engineer, General Electric Co.; residence 10 Gillespie St., Schenectady, N. Y.	C. P. Steinmetz. W. B. Potter. A. H. Armstrong.
ANTHONY, JAMES STOWELL,	General Electric Co., 44 Broad St., New York City.	Gano S. Dunn. C. D. Haskins. T. C. Martin.
BADEAU, CHARLES CUSHING,	Switchboard Engineer, Wagner Electric Manufacturing Co., St. Louis, Mo.	J. F. Badeau. F. Schwedtmann. W. A. Layman.
BAILEY, THEO. P.,	Assistant Manager, Chicago Office General Electric Co., 1047 Monadnock Building, Chicago, Ill.	H.M.Brinckerhoff. B. J. Arnold. R. H. Pierce.
BRISLEY, EDWARD BETTS,	Student, Stevens Institute; residence, 102 W. 75th St.; New York City.	A. F. Ganz. W. E. Geyer. J. E. Denton.
CLARK, WALLACE S.,	Engineer, Wire, Cable and Tube Department, General Electric Co.; residence, 13 Front St., Schenectady, N. Y.	C. W. Rice. W. S. Barstow. H. G. Stott.
COLE, WILLIAM WEEDEN,	Vice-President and General Manager, Elmira Water, Light and R. R. Co., Realty Building, Elmira, N. Y.	R. T. E. Lozier. J. B. Cahoon. W. E. Baker.
CUTLER, JAMES ELMER,	Manager of Philadelphia Office, Stanley Electric Mfg. Co., 26 So. 15th St.; residence, Overbrook, Philadelphia, Pa.	W. L. Adams. J. F. Kelly. C. Van Deventer.

EDMONSTON, EDGAR DAVIS, Electrical Engineer, The Lackawanna Iron and Steel Co., 401 Delaware Ave., Buffalo, N. Y.	C. F. Scott. W. S. Franklin. N. W. Storer.
EKSTRAND, CHARLES, Superintending Engineer, Brooklyn Cooperage Co., Brooklyn Elevator and Milling Co., and Palmer's Docks, Foot North 6th St.; residence, 74 South 9th St., Brooklyn, N. Y.	W. A. Anthony. F. S. Holmes. F. S. Woodward.
ELLINGER, EDGAR, Electrical Engineer, George A. Fuller Co.; residence, 215 E. 79th St., New York City.	Henry Morton. W. E. Geyer. A. F. Ganz.
GRAY, CLYDE D., Assistant in Electrical Department, J. G. White & Co., 29 Broadway, New York City; residence, 50 Pierrepont St., Brooklyn, N. Y.	H. J. Ryan. H. A. Lardner. G. L. Hoxie.
HELLEBUCK, GUSTAVE J., Electrical Engineer, Mediterranean Thomson-Houston Co., 5 Piazza Castello, Milan, Italy.	E. Thurnauer. A. S. Garfield. E. W. Mix.
HINES, CHARLES HENRY, Superintendent Electrical Department, Lorain Steel Co., 544 14th Ave,. Lorain, Ohio.	E. A. Merrill. M. L. Mora. W. G. Ely, Jr.
HOLMAN, GEORGE ULYSSES GRANT, General Manager, The Canadian Electric Light Co., Ltd., 12 Laporte St., Quebec, P. Q.	H. W. Blake. W. C. Andrews. T. C. Martin.
HOUGH, BENJAMIN KENT, Sales Engineer, Stanley Electric Mfg. Co., 1601 Empire Building, New York City.	C. A. Stone. E. S. Webster. J. F. Kelly.
HUMPHREY, CALVIN B., Office Manager, Westinghouse Electric and Mfg. Co., 711 Neave Building, Cincinnati, Ohio.	C. F. Scott. Arthur Hartwell. C. A. Terry.
HUNT, CHARLES WALLACE, President, C. W. Hunt Co., Stapleton, New York.	J. M. Smith. Elihu Thomson. T. C. Martin.
JUDSON, HANFORD CHASE, Assistant Engineer, General Electric Co., Dobbs Ferry, N. Y.	Eugene Griffin E. H. Mullin. T. C. Martin.
LEBLANC, MAURICE, Consulting Electrical Engineer, Westinghouse Electric and Mfg. Co.; residence, Villa Montmorency, Paris, France.	T. C. Martin. J. W. Lieb, Jr. C. A. Terry.
MCNARY, CHARLES HERBERT, Superintendent of Provo Station, Telluride Power Co., Provo; residence, Nunn's, Utah.	P. N. Nunn. C. A. Adams. S. E. Whiting.
MILES, J. WALTER, Electrical Engineer, Westinghouse Electric and Mfg. Co., East Pittsburg;residence,Irwin,Pa.	C. F. Scott. L. A. Osborne. H. W. Fisher.

MILLER, DWIGHT DANA, Salesman, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City; residence, Upper Montclair, N. J.	C. F. Scott. P. T. Brady. E. W. T. Gray.
MURPHY, GEORGE R., Engineer Operating Department, The Electric Storage Battery Co.; residence, 65 W. 93d St., New York City.	G. F. Sever. F. B. Crocker. Aug. Treadwell,Jr
O'DONOVAN, LEO J., Student, Columbia University, residence, 302 W. 72nd St., New York City.	G. F. Sever. F. Townsend. A. E. Poirier.
SHELDON, EDWARD ELLIS, Electrical Engineer, Hudson River State Hospital, Poughkeepsie, N. Y.	G. C. Van Buren. G. A. Redman. W. S. Andrews.
SHORT, SIDNEY HOWE, Technical Director, The English Electric Mfg. Co., 112 Cannon St., London, E. C., England.	W. D. Weaver. T. C. Martin. H. W. Blake.
STORER, SIMON BREWSTER, Engineer and Salesman, Westinghouse Electric and Mfg. Co., Syracuse office, 902 University Block, Syracuse, N. Y.	C. F. Scott. P. T. Brady. P. M. Lincoln.
STOVEL, RUSSELL WELLESLEY, Electrical Engineer, Pittsburg and Lake Erie Railway, Coraopolis, Penn.	J. J. Bellman. Clarence Thomson. L. A. Herdt.
WADDELL, CHARLES EDWARD, Electrician in charge Electrical Department, Biltmore Estate, Biltmore, North Carolina.	T. V. Bolan. Theo. Stebbins. S. J. Smith.
WELLMAN, HAROLD ROBINSON, Electrical Engineer, Motor Department, General Incandescent Arc Light Co., 572 First Ave.; residence, 3 Beech Terrace, New York City.	P. J. Kruesi. J. H. Hallberg. M. J. Insull.
WEST, ERASTUS LOVETTE, Assistant to Electrical Engineer, J. G. White & Co., 29 Broadway, New York City; residence, 50 Pierrepont St., Brooklyn, N. Y.	H. A. Lardner. H. J. Ryan. Maurice Hoopes.
WHITE, FRANCIS JOSEPH, Student, Columbia University; residence 53 St. John's Place, Brooklyn, N. Y.	F. B. Crocker. G. F. Sever. A. E. Poirier.
WILSON, NORMAN JAMES, Electrical Engineer, British Westinghouse Electric and Mfg. Co., Ltd., Trafford Park Works, Manchester, England; residence. 804 Wood St., Wilkinsburg, Pa.	C. B. Auel. N. W. Storer. E. M. Tingley.
WOODBURY, DANIEL CORYTON, Student, Stevens Institute of Technology; residence, 934 Bloomfield St., Hoboken, N. J.	A. F. Ganz. W. E. Geyer. J. E. Denton.

YORKE, GEORGE MARSHALL,	Assistant Electrician, American Telephone and Telegraph Co.; 15 Dey St., residence, 44 Irving Place, New York City.	G. T. Hanchett. A. P. Allen. F. A. Pickernell.

Total, 36.

The following associates were transferred to membership:

Approved by Board of Examiners, March 14, 1902.

WILLIAM CARPENTER WOODWARD, Electrical Engineer, Narragansett Electric Lighting Co., Providence, R. I.

FRANK POWELL COX, Electrical Engineer, General Electric Co., Lynn, Mass.

PRESIDENT STEINMETZ:—Gentlemen, the subject of to-night's papers and discussion is " Electric Elevators, Electric Hoists and Telpherage." The nature of these applications of electricity is that of intermittent service, similar therefore, to a certain extent, to electric railroading; and indeed, both the electric elevator and the electric railroad are solutions of the problem of electric locomotion, the difference being that in the electric railway the motion is essentially in a horizontal direction while in the elevator it is in a vertical direction. There are also intermediaries whereby the two types of locomotion are more or less connected with each other; on the one side in the rack railroad, on the other side in the inclined elevator. From these different kinds of motion follow the differences, as well as the similarities, between the two types of service, and the distinction in regard to the solution to be applied to the problem in the electric railway, which is approximately a horizontal motion, the load on the motors at normal steady speed running being very small compared with the load put on in special cases, for example, when climbing grades, or especially in starting. This means that the starting torque has to be very greatly in excess of the average running torque. At the same time, however, no limit is imposed on the speed by the problem of railroading, because when a railroad car is without power applied, its normal condition is that of rest. On a down-grade the car may be accelerated, but no grade can exist, that is to say, no grade that may be climbed as up-grade by the car, can be so steep that the car cannot be held against gravity by the torque. In other words, the danger of the running away of a car or train is a consideration of relatively secondary importance in the railway car. Furthermore, the distances are such that the only danger that has to be guarded against is that of collision. The problem with the elevator is different. Here we have motion in a vertical direction, with or against gravity; that means that even if the elevator car is balanced more or less, or over-balanced, we still have a condition where the load, without power applied or without torque applied, is not stationary, but work is done upon it by gravity. Therefore, we have either to work against gravity, that is, do continuous work in addition to the friction, in retaining the car in steady speed motion, or we have to hold back. Here we still require the excess torque in starting; but since the average load in the elevator is relatively much higher than is the case in the railroad problem, the proportion between starting torque and average running torque of the elevator is much less. That means that while the electric elevator still requires an excessive starting torque, this starting torque is not so enormous as in the electric railway, and less margin is sufficient. At the same time the normal condition of the elevator car without power applied is not rest, but motion. Under acceleration of gravity, it is essential to have some holding-back or speed-limiting device, and for elevator service, therefore, we require a motor having a limited speed, which it cannot exceed essentially, but beyond which it works back as a brake. You see then that there are two conditions imposed on the elevator service, the heavy starting torque and the limiting speed, to a certain extent antagonistic, because the former requires a motor of the type of the series motor, and the latter requires a motor of the type of the shunt motor or alternating current induction motor. The condition of limited speed does not exist in the electric railway service, but the other condition is more severe. We can see that while in their intermittent character, in their general principle of locomotion, of starting and of acceleration, steady speed running and retardation, the two classes of service are fairly similar, still the solution of the problem must lead to the use of different types of motors; in one case to the series motor, a motor with excess starting torque and no limiting speed; in the other case to a motor which is more or less a derivation of the shunt motor, namely, a compound motor; that is, a motor in which a shunt winding with its property of limiting the speed is combined with a series winding, which remains in circuit at starting, thereby reducing the speed, and increasing the torque in proportion to the load, and is usually cut out after steady running has been reached.

Thus far we have spoken of the relation between the electric elevator service and the electric railway service as akin to it. As regards electric hoisting, considerations apply similar to those governing the electric elevator service, except that in the hoist, as a rule, freight only is carried and the speed is very much lower than in the passenger elevator. Therefore, the problem is rather simpler, for not the same absolute safety as regards running away or getting out of control is required as in the high-speed passenger elevator. I may say, however, as regards the comparison between the electric and other types of operating machinery, of which the most prominent is the hydraulic, that the hydraulic has some very important advantages. The hydraulic cylinder and piston constitute a very steady, smoothly operating motor. However, it has the disadvantage of a very low efficiency. With the electric motor, naturally, the power required by the elevator corresponds to the load, or rather where the car is balanced for average load the power given by the motor is the friction load plus the power corresponding to the difference between the actual load and the average load. The hydraulic cylinder, however, requires the same volume of water at all loads. Whether the elevator is moving fully loaded or is running light, this cylinder must be filled, and therefore the power consumption does not vary with the load. This statement refers obviously to the case where the water is supplied at a constant, definite pressure, say at the pressure of the city water service. Where the pressure of the water may be varied according to the load on the elevator, the hydraulic elevator may be operated very efficiently; but in that case the elevator must be equipped with some motor which varies in power consumed in correspondence to the load, as, for instance, the electric motor. This has been done long ago, and is done now—hydraulic elevators are operated by electric motors, the electric motor merely pumping water to supply the hydraulic piston. That is rather an indirect method, so it is not necessary to dwell on it. The essential advantage of the electric motor is its high efficiency, because the power consumption is proportional to the load only, and there is no power consumption when not loaded, while this is not the case with most other types of motor.

Now, I request Mr. Sever to give his paper on "Power Consumption of Elevators Operated by Alternating and Direct Current Motors." Probably it would have been better, judging from the results of the paper, to say "by direct current and alternating current motors."

MR. GEORGE F. SEVER:—Mr. President and Members of the INSTITUTE: Some time last fall, Mr. Rice, the Chairman of your Committee on Papers and Meetings, suggested that an interesting paper could be prepared on the comparative cost of power for alternating and direct current elevator motors. An investigation was started with the results given in the following paper. The data presented has been gathered by three of the senior students in electrical engineering at Columbia University, and the records have been made with particular care in order that they might be authentic. Undoubtedly some minor errors have crept into the records which appear in this paper, but these will be corrected. We have been very ably assisted by the elevator manufacturers and the manufacturers of the electric motors. The endeavor has been made to present concrete and reliable results.

A paper presented at the 164th Meeting of the American Institute of Electrical Engineers, New York and Chicago, April 25, 1902.

POWER CONSUMPTION OF ELEVATORS OPERATED BY ALTERNATING AND DIRECT CURRENT MOTORS.

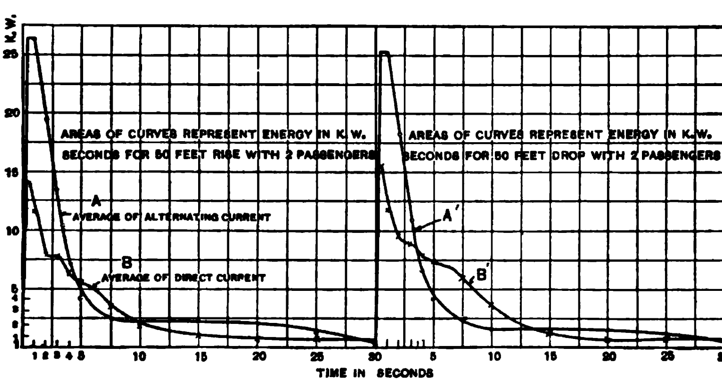
BY GEORGE F. SEVER.

The record of electrically operated elevators in New York City shows that there are approximately 3,000 operated by direct current motors, and 300 operated by alternating current motors. One reason why this disproportion exists is that the direct current motor has been available for a longer period than the alternating. Another is the uncertainty as to the amount of power necessary for each. If the consumption of power for one type of elevator makes its operation more expensive than another, but the use of this type overbalances any disadvantages possessed by one which consumes less power, then it will be the more desirable machine. Certainty of operation due to simple controlling devices, great overload capacity permitting the elevator to be operated under unusual conditions, are two important requirements. If the alternating current motor cannot fulfill these requirements economically, we find immediately another explanation for its small application as compared with the direct current motor. When the location of the apartment house or office building is such that it is not possible to secure direct current for the operation of electric elevators, it is of course necessary to use the alternating current. In some sections of the city it is at present impossible to obtain a direct current supply and the users of elevators have been of necessity compelled to install the alternating current system.

It was brought to the writer's attention that there was considerable difference of opinion as to the consumption of power for the two different types of electric elevator, one using alter-

nating and the other direct current. In the hope of bringing forth further facts concerning this matter, investigations were undertaken to determine the power consumption in the two different lines. The work has been successfully conducted by Messrs. Rosenblatt, Daniels and Haviland, senior students in the Electrical Engineering Department of Columbia University, by making numerous tests on elevators of the different types providing similar service. Twenty such tests have been made and the results of the most characteristic installations are given in the appended table. The first five relate to direct current and the subsequent tests to alternating current motors.

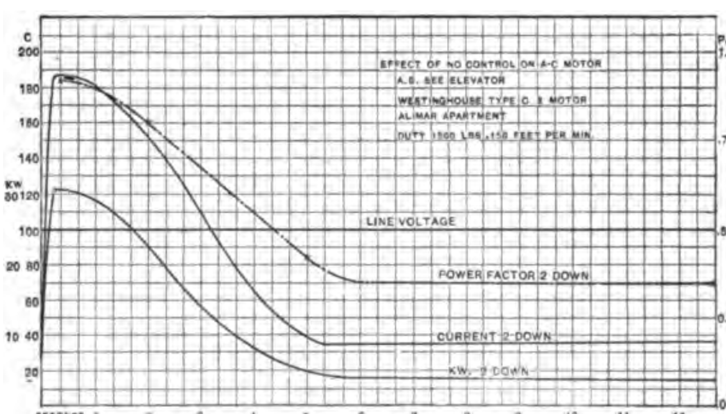
It will be noticed that these investigations have been made in widely different sections of the city, with the alternating cur-



Curve Sheet Nos. 1 and 2.

rent installations in that part where direct current is not available. The types of control for the direct current motors are known as magnet control, although No. 3 is regulated by hand. Four of the alternating current motors have no method of control, the current being thrown directly on to the motor by a switch. No. 10 has what is known as a two-voltage control, using two transformers, one giving 60 volts for starting and the other 175 volts for the running voltage. No. 11 has a rheostat control. This is arranged in such a way that resistances are altered in the rotor of the alternating current motor giving four steps from stand-still to full speed.

One very interesting point in connection with the alternating current motors is the power factor. It will be noticed that the starting power factor varies from .79 to .97, according to the load upon the motor. In contrast to this, the power factor, while the elevator is running, varies from .14 to .68, the average being .36. This shows that the alternating current motor is much larger than the average conditions would call for, but it seems necessary to provide this capacity in order to accommodate any heavy loads that may have to be carried on a few occasions. The inrush of current for the alternating current motors is large as compared with that for the direct current machines, especially in those cases where there is no control. In test No. 11 with the controlling system using resistances in the motor, the inrush currents are maintained at a value comparable with those used in the direct current motors.

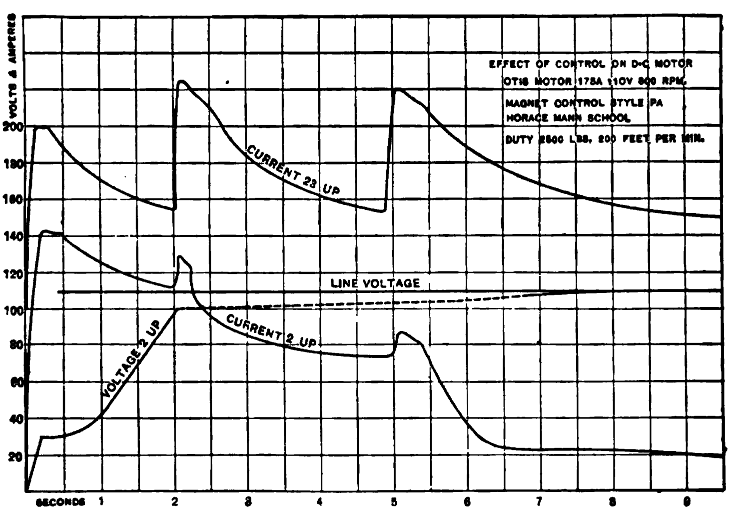


Curve Sheet No. 3.

In test No. 1 of a direct current elevator with 23 people carried up, the current at starting, is 199 amperes with running current of 150. In tests Nos. 6 and 8 with only two or three people carried up and down, the current varies from 170 to 193. In comparing the kilowatts for starting in these two cases, we find 19.8 for the direct current elevator and from 29.6 to 34.7 for the alternating current machines. Test No. 11 would seem to indicate the method by means of which the power consumption for alternating current motors may be decreased and thereby make the cost of operation less than it is at present for similar types of machines.

The above tables simply indicate the actions of the various types of elevators, and it is not advisable to compare the two classes of elevators as to economy from the results shown. In order that a comparison might be made between all the tests which were conducted, curve sheets Nos. 1 and 2 were prepared.

Curve sheet No. 1 shows the average energy for all elevators through a rise of 50 feet carrying two passengers, the energy being expressed in kilowatt-seconds. Curve sheet No 2 shows similar values for the descent of the elevator. Curve A on curve sheet No. 1 shows the average of the alternating current and curve B that for the direct current tests. The areas of these two curves are to each other as 1.509 is to 1. This shows a percentage against the alternating current elevators of 33 per cent. Referring to curve sheet No. 2, and comparing the al-



Curve No. 4.

ternating current curve A1 with the direct current curve B1, we find a relation of 1.079 to 1, showing a power consumption for the alternating current machines greater by about 8 per cent. The curves for the direct current tests are made from the results of five motors with automatic control, while the results for the alternating current machines are made from six uncontrolled motors.

Curve No. 3 shows a typical alternating current motor with no control. The starting current with elevator going down is 186 amperes, while the kilowatts at this point are 30-5. The course of the power factor is interesting, it being. 92 on starting, rapidly falling to .35 when the elevator is running at a uniform speed. Curve No. 4 shows the effect of control on direct current motors with a considerable overload. The current with 23 people in the car rose to 200 amperes and made an upward jump, reaching 225 amperes at the next point in the control. The variation in the voltage across the motor is shown by the voltage curve and this record would seem to indicate that the resistances of the circuit could be increased to advantage.

With the cost of power at ten cents per horse-power hour for both types of elevator, it would appear more economical to use direct current elevators in those places where both direct and alternating current are available. If the controlling apparatus is more simple with the alternating current system and the absence of a commutator on the motor can be counted as an advantage, the extra expense of operating an alternating current machine might be offset by the decrease in repairs and attendance. Apart from the last considerations there seems to be every advantage in favor of the use of the direct current motor.

A paper read at the 164th Meeting of the American Institute of Electrical Engineers, New York and Chicago, April 25, 1902.

TELPHERAGE.

BY CHARLES M. CLARK.

Definition. Telpherage is derived from two Greek words "τελε" and "φερω." "Tele" means far, and "ferro" means to bear or to carry. Therefore, telpherage means far-carrying. The same word "tele" appears in telegraph and telephone. The word was originally invented by the late Professor Fleeming Jenkin, who was the early spirit of telpherage, and but for his untimely death, telpherage would be even more extensively used. Like many other words, its meaning has varied. In the beginning it meant, practically, aerial electrical transportation, but now it has been brought back to its original meaning, which is the transportation of material to a distance by electricity, overhead, or sometimes on the surface, or even underground. In the latter case, it is termed "tubular despatch." Therefore, telpherage may be concisely defined as the electrical transportation of material. The method of applying it is an engineering problem and must depend upon local conditions, and even to-day the term "telpherage engineering" is becoming a common expression. It will be noticed that the word "automatic" is left out in these definitions. The reason for this is that it is a commercial question, and in cases where a man is required to attend to certain portions of the work, it is often cheaper for the man to go with the load than to use automatic devices. As to whether it is better to make an installation automatic or otherwise, depends entirely upon the comparative cost of the two methods of operation. In this connection it may be said that with telpherage plants the word "telpherman" is now often used.

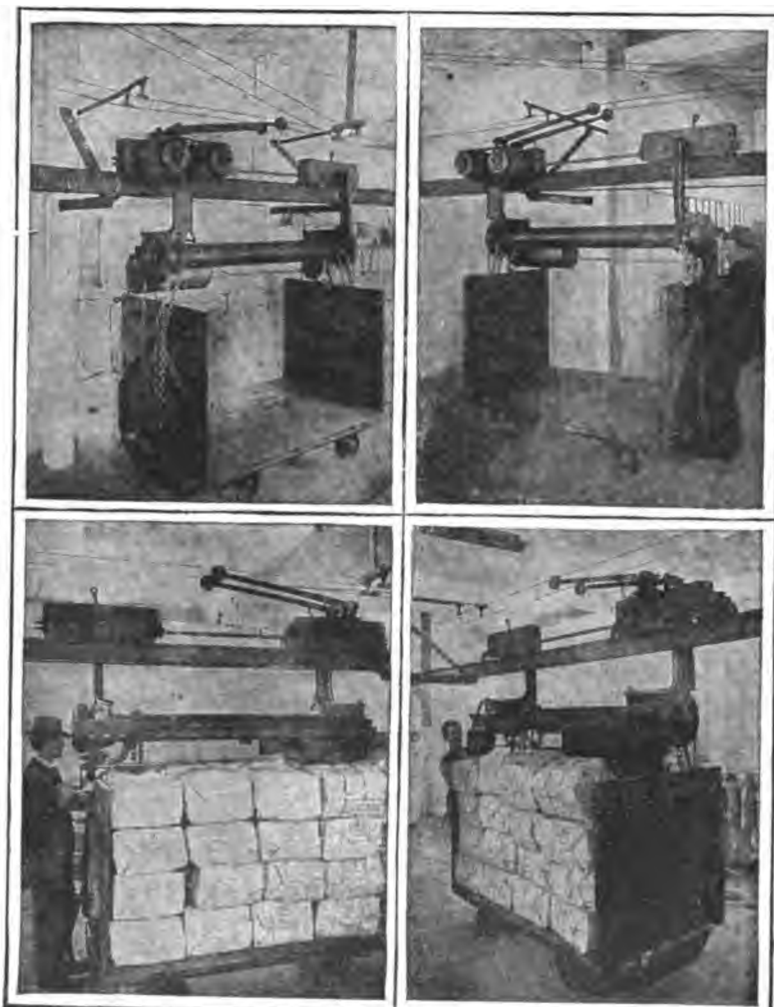


FIG. 1. Side bearing telphers with permanently attached trailer. Track solid rail. Telpher controlled from either end. Length 1,200 feet. Four curves one "S" curve. Grade 12 per cent. Maximum total 4,000 lbs. Speed on level 10 miles per hour. Speed on grade 5 miles per hour Horse power—5 horse power. Capacity, 100 tons per day per telpher.

History. The early history of telpherage closely resembles that of the electric railway. Before the successful pioneers in electric street railway traction had finally accomplished satisfactory results, many men had experimented, and it is well known that, some forty years ago, an electric railway was operated, having a speed of several miles per hour. It seems that it is necessary, with all successful applications of power to the transportation problem, that much preliminary work, seemingly unproductive, must be done. It often happens, as in the case of early telpherage, that the time was not ripe for its commercial adaptation. In the history of telpherage in England, a telpherage line was installed, using what was then called the series system, whereby it was necessary to use a telpher with a number of trailers. One section was positive and the next negative, the current passing from one section of the track to

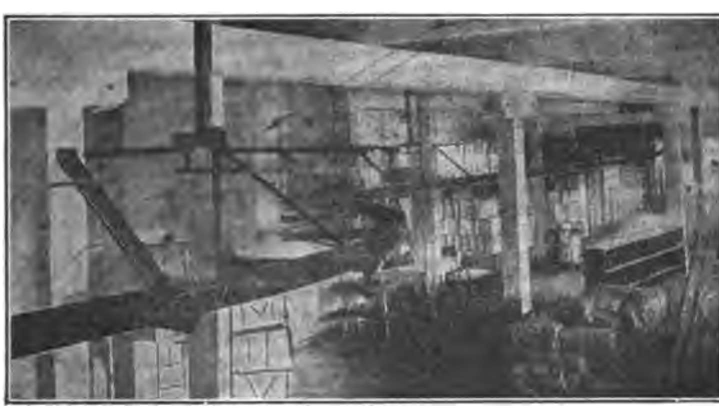


FIG. 2. Track of above showing "S" curve.

the other through the motor, thereby completing the cricuit. In passing over the insulator between the positive and the negative sections, there necessarily occurred considerable sparking, which greatly increased the cost of maintenance. It was also necessary always to have trains of certain lengths. There were many other disadvantages, such as having to use a track made of round bar rail and the difficulty of manufacturing reliable electric motors. If it was desired to install a telpherage plant, it was always necessary to put in an engine, boiler and dynamo. In comparison with its early history, telpherage to-day possesses the advantage that every factory, where there is need for telpherage, either has its own electrical plant, or the power may be rented from existing central stations or even street railway stations. There are also to-day for aerial transportation most excellent cables made especially for telpherage work, and likewise, where it is more desirable to use than solid rail cable, special shapes have been devised which give most excellent results. Motors, controllers and carriers of great reliability are now manufactured following the methods developed by the best railroad practice.

Before it was decided to enter into the present commercial adaptation of telpherage, an engineer visited all the electrical manufacturing plants and electrical installations in Europe, and found that nothing was being done in the transportation of material electrically. In the United States many experiments had been made, but the inventors were always seeking the unobtainable. Upon careful research, it was found that there were 450 patents directly applying to telpherage and several hundred more which pertained indirectly to this subject. Most of these original inventors, were, however, too ambitious, and there was hardly any limit to the number of miles per minute which was to be achieved by the new and wonderful agent, electricity. Not only material was to be transported, but also passengers, and beautiful cars of mahogany were built and put in experimental operation. Cigar-shaped carriers were devised, some of which made a speed of two miles per minute or more, and when it was impossible to attain a greater speed there was great discouragement. There are no authentic examples of much more than experimental work, namely, merely conveying material between two points, generally in a straight line, placed in some vacant lot or loft, and there seemed to be a desire to force the method of transportation according to certain preconceived ideas, rather than to pay the necessary attention to its commercial adaptation.

Construction. On account of various advantages in regard to the distribution of material—such as depositing at an elevation—most of the telpherage plants thus far installed, have been overhead. As engineers, you will be most interested in hearing what has been accomplished; the descriptions are, therefore, confined to overhead work. Under the head of construction, it may be stated that the track is made of cable, especially drawn, either of standard wire or lock coil type, which latter has a strength approximating 95 per cent. that of the solid bar, or else solid rail, either of flat, girder or bulb type.

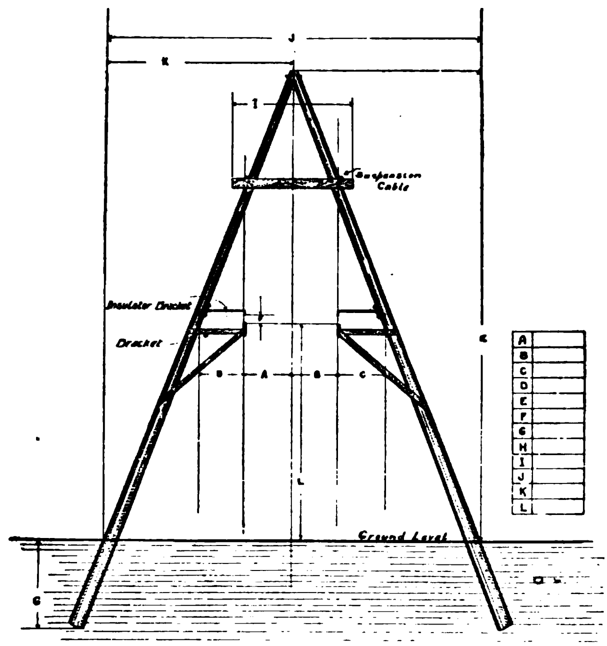


FIG. 3. SUPPORTING POLE, DOUBLE LINE. One of the simplest methods of pole construction for double lines. Especially recommended for long lines and where trees are available.

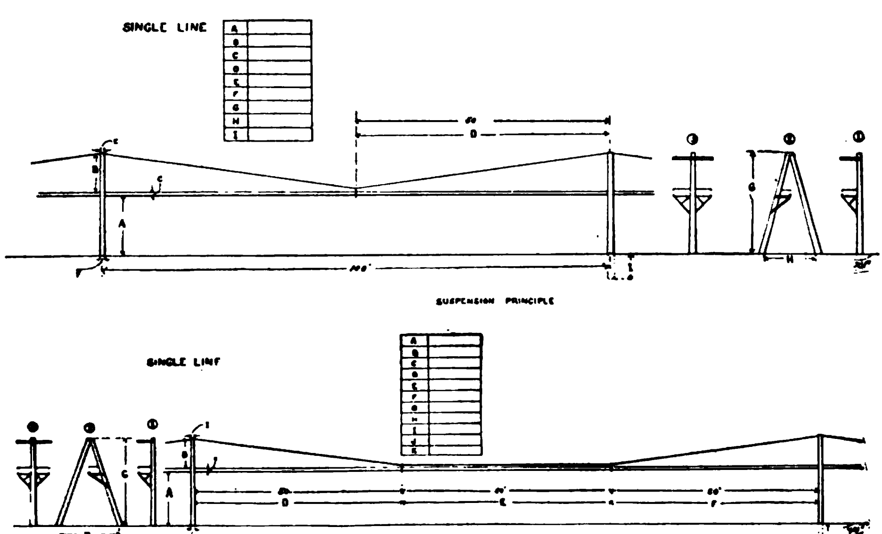


FIG. 4. OTHER FORMS OF POLE CONSTRUCTION, SHOWING SINGLE AND DOUBLE LINES. The track cables are supported by another cable, which is called the suspension cable. It would be impossible with long spans to stretch a cable so that under load there would not be considerable deflection. This deflection or sag is taken up by the suspension cable. Not only can we make the track cable horizontal, but even higher in the center than at the terminals.

The cable tracks are supported every hundred feet, provided it is convenient to erect poles or structures. Where there are deep ravines or between upper stories of factories, the span is made to correspond with the distance, and may be made of any reasonable length. In addition to the track cable, upon which the telpher runs, there is also what is known as the suspension cable. As is well known, it would be impossible to prevent considerable sag in the track cable and therefore the track cable is suspended from this suspension cable by means of hangers. The number of these hangers depends upon the length of the span. It will be easily seen that it is possible to have the

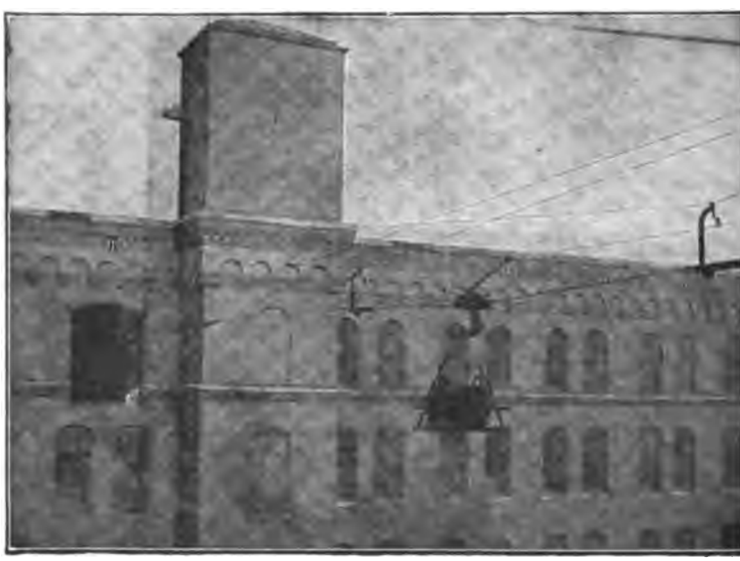


FIG. 5. Cable construction, Pittsburgh, Pa., line 97 feet from the ground, illustrating suspension cable, track cable and hangers.

center of the span higher than the ends, by merely raising the suspension cable and the hanger. This obviates one of the early difficulties met in the use of cable for telpherage, as there is now no objectionable deflection in the cable when the telpher approaches a bracket. There are several methods of connecting the track and suspension cables by means of the hangers. The sizes of the cable, hangers and brackets vary, depending upon the weight which comes upon each individual span. The support is either simple poles with a bracket, or what is known as the "A" construction or ordinary cross bents. Cable construction costs less than solid rail, except where there are many switches, in which cases the prices of solid rail and cable approach each other. In general, cable lines is recommended for straight lines, except where the weight is excessive.

In solid rail construction, the supports are ordinarily placed sixteen to twenty feet apart; longer spans are used if it is not convenient to erect supports. On long spans, the track consists of a girder rail with the track rail above it. It is not possible to give any general rule, as to what kind of track it is advisable to use, as this is a factor of the length of the spans and the

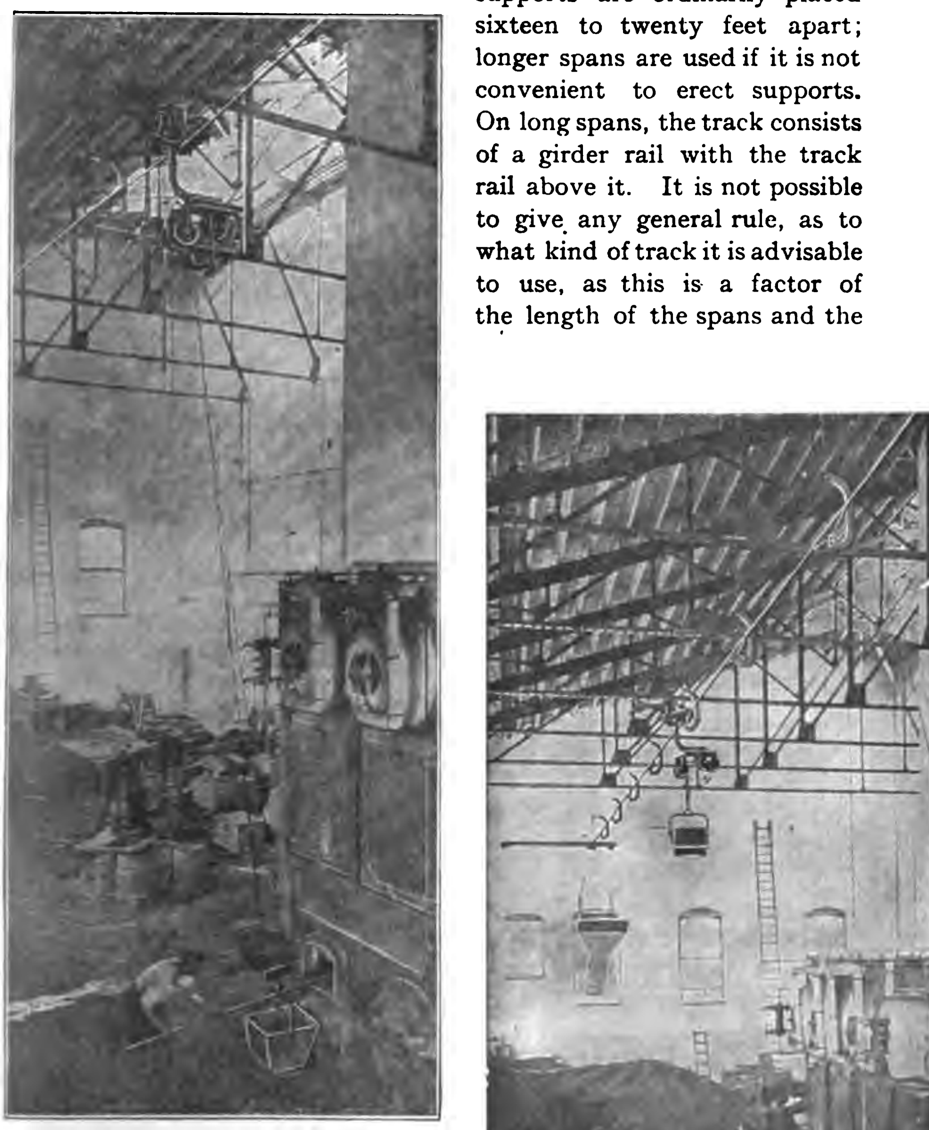


FIG. 6. Examples of cable construction with telpher, electric hoist and bucket, Elizabethport, N. J.

weight. The weights conveyed thus far by telpherage vary from 125 to 10,000 lbs. and the cost varies accordingly. It will be readily understood that when the weights are greater, the supports must be nearer together, and the cables or girders heavier. Running parallel to the track rail, either above or at the side, depending upon the amount of head room, are stretched one or more trolley wires; one wire, if the track is used as a return. If, however, it is desired not to use the track as a return, or to use alternating current, two trolley wires are employed. There are many other details of construction, but the photographs and outline drawings will serve to illustrate better than any description.

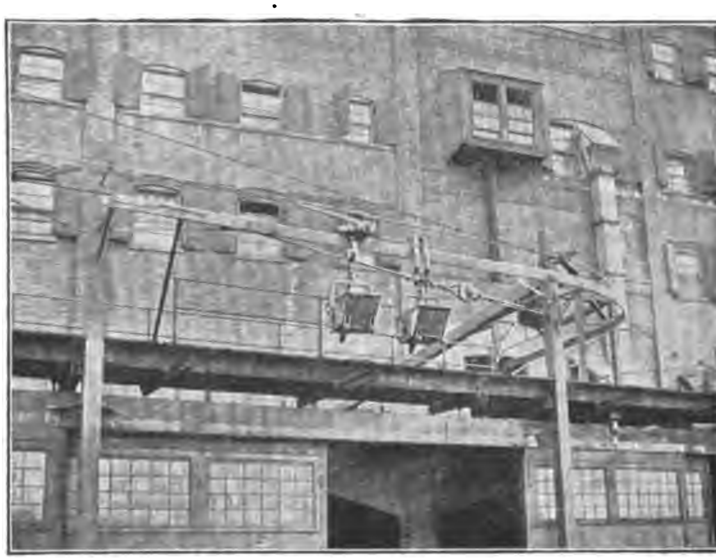


Fig. 7. Solid rail combined with cable construction. Capacity, 150,000 lbs. of ashes in ten hours. At present, handling the ash output of 23 boilers with other refuse. Average power consumed about one horse power. Located in New York City.

Telphers. According to the construction, telphers are divided into three distinct classes, center bearing, side bearing and alternate bearing. The center bearing has two motors, one on each side of the track; the side bearing has both motors on the same side, and the alternate has one motor upon one side of the track and the other motor upon the other side, but not upon the same shaft. Illustrations of each kind (Figs. 8, 9, 10, 11 and 12) are shown, also the same in operation. All the weight, in the side-bearing telpher, is utilized for traction, and the load is suspended

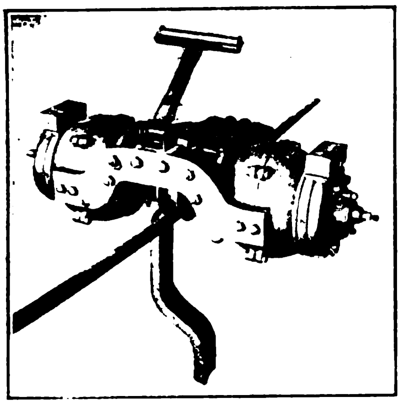


FIG. 8. CENTER-BEARING TELPHER.

FIG. 9. TELPHER WITH SOLENOID SPEED REGULATOR FOR GRADES AND REVERSING SWITCH.

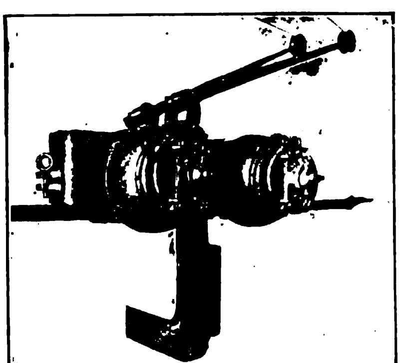


FIG. 10. FRONT VIEW. SIDE BEARING. DOUBLE TROLLEY.

FIG. 11. SINGLE TROLLEY. SIDE BEARING.

FIG. 12. Side bearing telpher in operation. Illustrating method of suspension, also the carrier, section insulator, hanger, suspension and track cables with trolley wire.

beneath the driving wheels. Sometimes two telphers are connected up together in a single truck, this giving what is called a double telpher; or a trailing wheel is used after a double telpher, in order to distribute the weight over a greater portion of the track. This is necessary when the weight of the load to be carried is great. Fig. 13 shows quite fully this weight distribution. In all telpherage work, gears are rarely used except for very heavy work or on steep grades. The frames of the later telphers are made in one casting, and the driving wheels are of steel, this having been determined to be the best material.

Motors. The motors are waterproof and dustproof and are compound wound for automatic work. When a telpherman goes with the telpher, the series winding is employed. There is also used a special series coil to give greater torque when starting. The telpher is placed above the track, thereby keep-

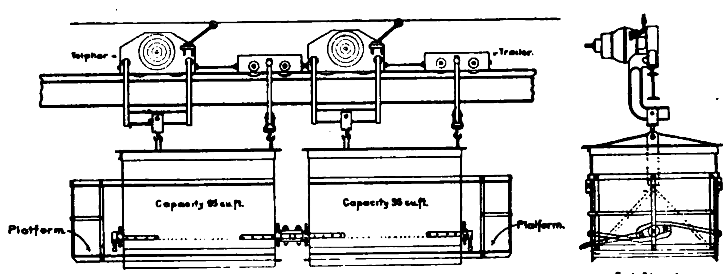


FIG. 13. The double telpher; maximum traction; capacity, four tons of coal, or 95 cubic feet; speed, 800 to 1,200 feet per minute. Side-dumping bucket operated by telpherman; controlled from either end. Telphers can be operated separately.

Three of these double telphers have a capacity of 250 tons of coal per hour over 2,000 feet of track. Labor, power and maintenance less than one cent per ton.

ing the motors from injury, while there is also no danger of their coming in contact with the carriers or being otherwise injured.

Hoists. The hoist is suspended below the telpher, or sometimes from a trailer drawn by the telpher. Special attention has been paid in the later designs of hoists to use as little head room as possible. It was deemed best at first to combine the telpher and hoist, but there were so many cases where it was necessary to use the telpher alone without the hoist, and also where it was advisable to put the hoist on the trailer instead of on the telpher, that experience has shown that it is better to make the telpher and hoist two separate pieces of apparatus. Greater simplicity has also been obtained, and a correspondingly lower maintenance reached. There are many other interesting details concerning hoists, as to the speed, lift and construction, which it is necessary to omit here.

Brakes. Two distinct types of brake are used on telphers, either hand brakes or solenoid brakes, both of which are arranged to apply pressure to the wheels or to grip the track. In regard to the solenoid brake, it is only necessary to explain that it works automatically, the solenoid being placed in series with the armature. A spring normally holds the brake on the

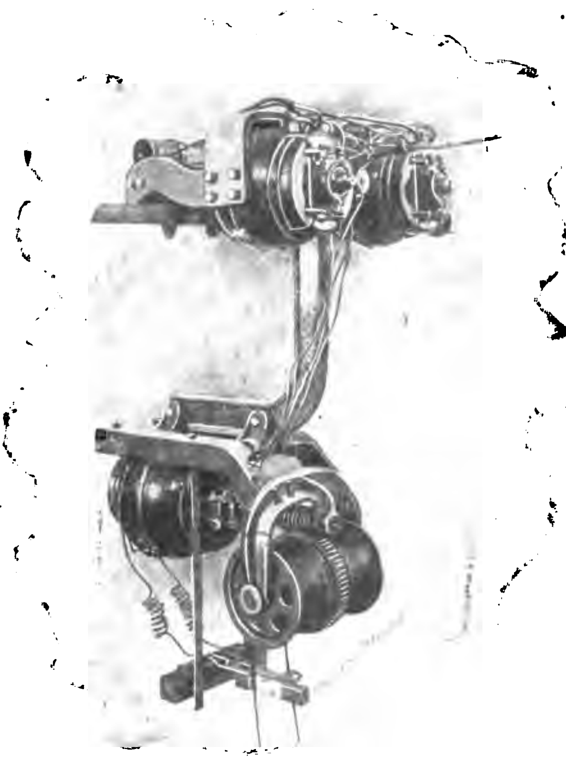


FIG. 14. ELECTRIC HOIST SUSPENDED FROM TELPHER.

wheel or the track. If, however, from any cause, the amount of current passing through the solenoid is reduced, whether by means of external resistance or by reason of the additional counter-electromotive force generated by the armature, due to running at a high speed, the solenoid becomes weakened and the brake is applied. An air cushion is arranged so that the brakes will be applied gradually.

Trailers. It is often advisable, where a large amount of material is to be carried, especially over one track, to use trailers. These consist generally of a two-wheeled truck, below which is suspended a bucket or other suitable form of carrier, or even the hoist, as the case may require. It is customary where a large amount of material is to be carried, to arrange a long train carrying as much as ten tons. The order of procession is, first, a telpher with four or five trailers, then another telpher and four or five trailers, and a telpher at each

FIG. 15. ELECTRIC HOIST AND TRAILER.

end. The placing of these telphers at intervals greatly adds to the traction, while the distribution of weight over the whole span, or over two or three spans, enables much lighter construction to be used for greater capacity.

Layouts. Much engineering skill is required to lay out or plan the telpher lines for any proposed work in order to decide whether the line should be single or double, and the weight to be carried by each unit. The installations should be so planned that the expense will be reduced to a minimum, and further, that the track will not interfere with existing machinery or buildings, taking care to avoid an excessive number of curves and switches, as these add more or less to the expense, particularly to the cost of erection. It is necessary therefore, for the selling engineer to be thoroughly trained in this part of the work, or else have the necessary engineering knowledge derived from some other similar business. It may readily be understood that it is impossible to give general prices for telpherage work. Complete specification blanks, with many necessary questions, are, therefore, provided, and the replies to these questions, together with a blue print showing a plan and elevation, are generally sufficient for the company to give a complete estimate for any proposed installation.

Method of Operation. It is difficult to treat in a general way of the method of operation. In automatic lines it is necessary to provide appliances whereby it is impossible for an unskilled operator to injure the telpher. In order, therefore, to provide for contingencies, a "dead section" is placed at each end of the line, the middle of the line being generally left alive. Upon closing a spring switch, the dead section is energized so long as the operator keeps his hand on the switch, which is usually only a few seconds, during which time the telpher passes to that portion of the line which is always alive. When it reaches the other end, it comes upon the dead section and then either slows down of its own accord, or else a mechanical or solenoid brake is applied. The telpher then passes under the reversing arrangement and it is therefore reversed, either with no current in the line or else with a high resistance. If the telpher is at the further end of the line, the operator at the near end, by closing a switch, can bring it back to him. The dead sections at the end of the line, which have current only so long as the hand is held upon the spring switch, render the line as safe as possible against the telpher coming in contact with the terminal posts. An automatic block system prevents collision of telphers.

Curves. The curves are solid rail and likewise the trolley track, where there is a curve, especially when it has a short radius. Wherever it is necessary to pass around a curve, to take turnouts or crossovers, a resistance is inserted in the trolley circuit, whereby the telpher automatically reduces its speed while it is traversing the curve or turnout or approaching a crossover switch. As soon as it reaches the other side of the curve it receives full voltage and continues at its normal speed. In regular service the speed varies from 300 or 800 feet per minute, up to 20 miles per hour, or even more, when required. The slower speeds are used when the lines are short and where there are many curves, particularly for factory and foundry

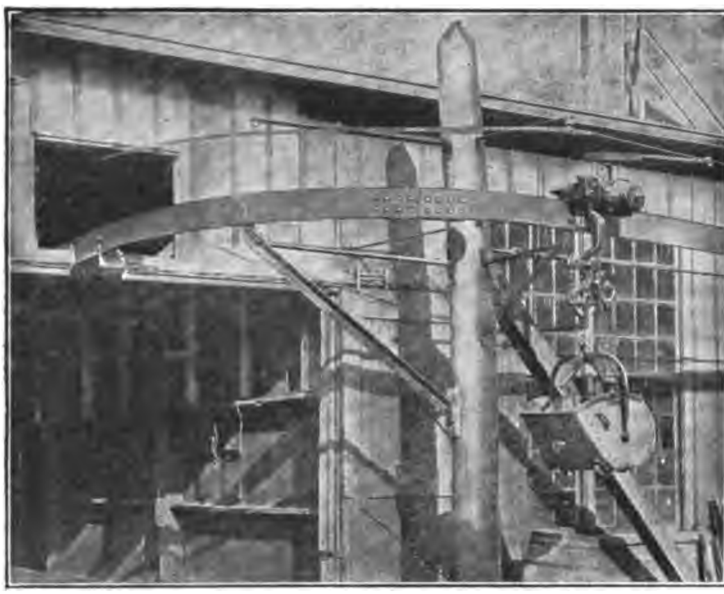


FIG. 16. TELPHER WITH AUTOMATIC DUMPING BUCKET TRAVERSING A CURVE. This shows a telpherage plant located at Buffalo, N. Y. This installation is interesting on account of its automatic features. The bucket is loaded at the cars and the load is transported by electricity to the end of the line, where the bucket automatically dumps its load. The telpher reverses itself and returns with the empty bucket to the cars for another load. The telpher may be operated by unskilled labor with the minimum of expense for power, maintenance and first cost. Power is less than one horse. The material which is dumped into a hopper is then elevated to the upper story. This line consists of a straight section and a right angle curve. A portion is cable, and the curve and the track in the building are solid rail. The line is supported, as will be observed from the photograph, from ordinary telegraph poles, and is an excellent example of simple construction.

work. For lines running across the country a speed in excess of 20 miles per hour can be obtained, but with the higher speeds the cost of the construction increases, certain special devices being necessary. Even for installations which are termed "cross country work," 15 to 20 miles per hour has been found amply sufficient.

As to what the ultimate capacity on grades may be, this has not been fully determined. Experimentally more than 20 per cent has been reached. In actual practice the greatest grade equipped has been 12 per cent., and thus far there seems to be ample traction.

THEORETICAL HORSE POWER NECESSARY TO PROPEL 1,000 POUNDS AT VARIOUS SPEEDS AND UP VARIOUS GRADES AT SAME SPEEDS.

Grades in per cent.	SPEED IN MILES PER HOUR.													
	1	2	3	4	5	6	7	8	9	10	12	15	20	25
0	.027	.053	.080	.107	.133	.160	.187	.213	.240	.267	.320	.400	.533	.667
1	.053	.107	.160	.213	.267	.320	.373	.427	.480	.533	.640	.800	1.07	1.33
2	.080	.160	.240	.320	.400	.480	.560	.640	.720	.800	.960	1.20	1.60	2.00
3	.106	.213	.320	.427	.533	.640	.747	.853	.960	1.07	1.28	1.60	2.13	2.67
4	.133	.267	.400	.533	.667	.800	.933	1.07	1.20	1.33	1.60	2.00	2.67	3.33
5	.160	.320	.480	.640	.800	.960	1.12	1.28	1.44	1.60	1.92	2.40	3.20	4.00
6	.186	.373	.560	.747	.933	1.12	1.30	1 49	1.68	1.87	2.24	2.80	3.73	4.67
7	.215	.427	.640	.853	1.07	1.28	1.49	1.71	1.92	2.14	2.56	3.20	4.27	5.33
8	.241	.480	.720	.960	1.20	1.44	2.68	1.92	2,16	2.40	2.88	3.60	4.80	6.00
9	.267	.533	.800	1.07	1.33	1.60	1.87	2.13	2.40	2.67	3.20	4.00	5.33	6.67
10	.293	.586	.880	1.17	1.47	1.76	2.05	2.34	2.64	3.03	3.52	4.40	5.36	7.33
11	.320	.640	.960	1.28	1.60	1.92	2.24	2.55	2.88	3.20	3.84	4.80	6.40	8.00
12	.346	.693	1.040	1.38	1.73	2.08	2.43	2.77	3.12	3.46	4.16	5.20	6.93	8.67

Although the amount of power may be easily figured out, it is somewhat in the nature of a surprise when we consider that to carry half a ton on a level track at a speed of six miles per hour, much less than a horse power is required, including all losses. This is a revelation to most manufacturers. The absence of gearing, the motors being attached directly to the driving wheels, gives the highest efficiency possible, as well as freedom from noise.

The actual power consumed, according to the table given above, at six miles per hour for 1,000 pounds on a level is only .16 h. p. It is, therefore, seen that ample allowance is made for losses and extra weights not provided for in the load, such as down-comes, buckets or carriers. The power required increases greatly with the grades and when this reaches certain limits it is deemed advisable to use gears in order to reduce weight of motors.

Maintenance. Although telpherage has not as yet been in operation for a sufficient number of years to determine exactly what the maintenance will be, yet, at the same time, in lines that have been operated for a year and a half, the maintenance has been exceedingly small. As stated above, the driving wheels being of steel, none of them has thus far shown any signs of wear, and trailer wheels are of the same material and type as those which have been used on mechanical cable lines for ten years and are still in good serviceable condition. The motors, on account of their elevated position, have shown a better maintenance than stationary motors of the same type. This may possibly result from the extra care taken in their construction. In regard to the track, this has also shown most excellent results, also due to the fact that it is above grit and dirt and crossing teams and, when well painted, has shown little signs of wear or depreciation. Wherever a change is made from cable to solid rail, or where cable passes over hangers or brackets, it is pro-

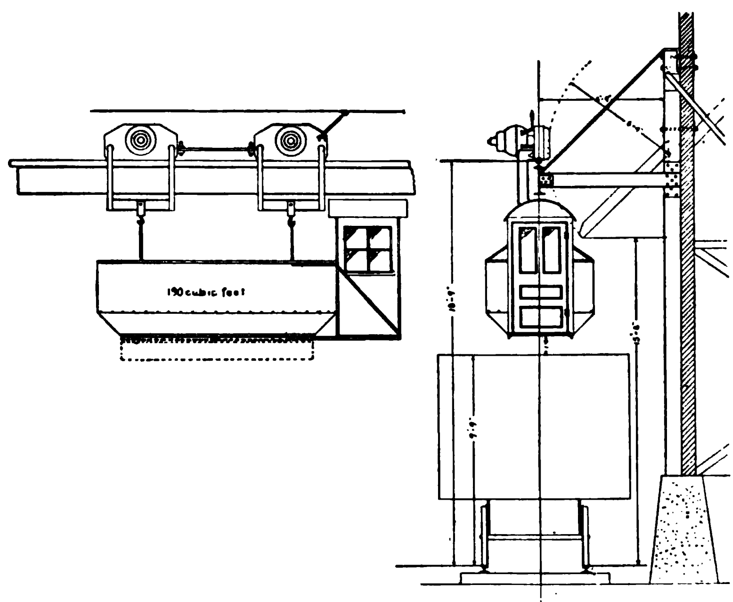


FIG. 17. Plan and elevation of another form of double telpher with four-ton coal bucket, bottom dumping, cab for telpherman. The side elevation shows method of attachment to side of building and loading chute.

tected by what are called "shields," these being arranged so that they may be readily replaced. The cable is also protected at the hanger and brackets by steel shields.

Capacity. An important feature in telpherage is the capacity of the line. In general, I can say that there is no other form of conveyor known which shows such flexibility. This is due to the use of electricity, and the features which apply to the street railway, apply also to telpherage. There are two factors of special importance in relation to the capacity of the line:

first, the speed, and second, the number of telphers and trailers. The line may be laid out with one telpher and a few trailers. More telphers or trailers may be added, and, if upon a single line, coupled in long trains. If it is desired still further to in-increase the capacity, the line may be made double, while if de-

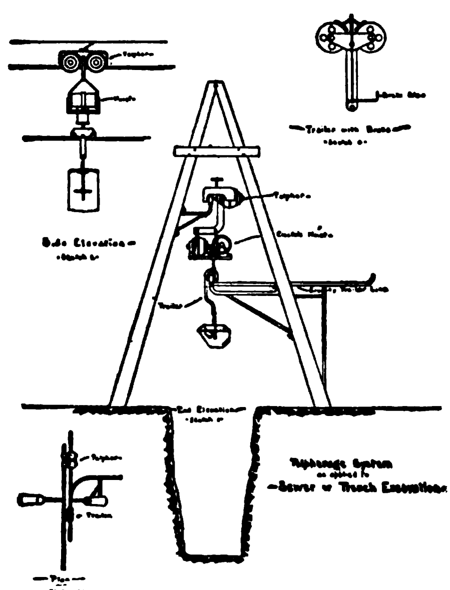


FIG. 18. In sewer or trench excavation the method of operation it as follows: The bucket has attached to it a trailer wheel. The buckets and wheel are lowered into the excavation. and the bucket, when filled, is raised by the electric hoist so that the wheel of the trailer engages the gravity rail. The load then passes by gravity to the place desired and is automatically dumped. This may be along the line of excavation, for refilling the trench, or to the right or left, for unloading into carts, or in connection with the telpher to any desired distance. The telpher has the flexibility of a trolley car. This method is a combination of telpher and gravity lines, and the amount of work that can be accomplished by it with the minimum of labor is remarkable.

sired, the carriers may also be made continuous so as to take boxes and barrels or other freight as fast as they can be delivered to the carriers of the telphers and trailers.

The flexibility of telpherage in regard to capacity is wonderful, and is a most important feature. In fact, it may be said that there is practically no limit to flexibility. In one plant, about to be installed, the proposed capacity is 250 tons per hour, over a distance of one-half a mile, the material to be distributed over an area of about an acre. Any one who is familiar with conveying will note that there is no other system that can do this so economically, and in a way so thoroughly satisfactory as telpherage.

The nature of installation varies with the amount of material to be carried, so that if the amount to be carried is small, the expenditure need not be great. Figs. 17, 18 and 19 show various applications.

Applications of Telpherage. There are few factories where the installation of an overhead telpherage system would not prove a valuable investment. The question is often asked: Is telpherage suited for carrying specific articles? And the reply may

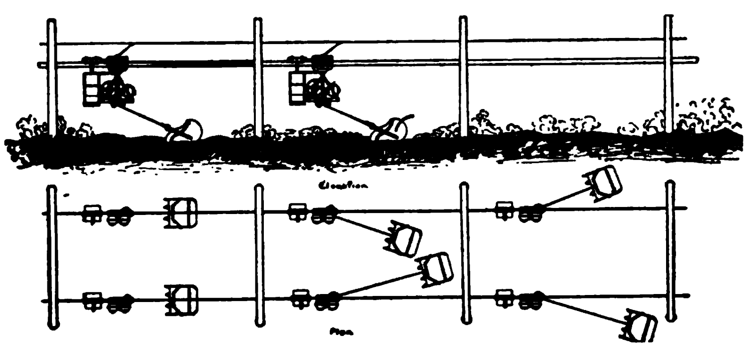


FIG. 19. Excavating and leveling in preparing roadbeds for railroads. The function of the telpher is to transport the hoist, bucket and load. The hoist does the excavating and elevating. The hoist automatically brakes itself either upon the girder rail or grips the cable as soon as there is any longitudinal strain. Used also for scooping and transporting earth, sand, ashes or coal.

be made that it is adapted to the conveying of the products of almost every kind of manufacturing.

In these days of consolidation of companies, factories cover immense areas. The individual buildings are frequently large enough in themselves to utilize a telpher line. In many cases, on account of fire risks or of convenience in manufacturing, the buildings are widely separated from each other, and yet constant communication is necessary. Overhead telpherage, therefore, in manufacturing establishments is used for carrying the raw material, implements and finished products from one part of the grounds to another, from one building to another, or, even from one part of a building to another part, moving raw material from cars or vessels to the works and then taking the finished products to the railway station, or the wharf, for shipment; and for conveying refuse away from the factory. In this connection we might mention the conveying of ashes or slag to the dump heap.

Telpherage may also be extensively used for handling coal. It serves to reduce greatly the cost of transportation on plantations and farms and may be economicallyused for handling coffee, sugar cane, tobacco, fruits and hay and other like products.

In general, it may be said, that wherever material is to be carried to a distance, there is no power so flexible, so economical in first cost of installation, costing so little for power or the expense of maintenance, and with such great capacity as telpherage. It may, therefore, be designated a material transportation by an immaterial fluid, and may well be called one of the most important of the many adaptations of electricity.

If time, floor space, or labor is being consumed in the conveying of any kind of material in any plant, plantation or mine, each can be saved by the installation of telpherage. Any condition at any manufacturing establishment which presents a requirement for hauling by man or team, whether in transmission of product during the various stages of manufacture, the movement of materials by which the product is to be treated or the handling of fuel, and ashes or other waste, is a logical opening for the installation of telpherage.

When you install telpherage you employ a machine to do the work of men. Machinery is the most powerful factor for economy in production. Telpherage is almost human in its operation, works any number of hours per day and never tires. In many cases you start the telpher, it conveys, automatically leaves its load at the destination and returns for another load. Telpherage conveys 50 lbs. or 50,000 lbs. solids or liquids.

Much more can be said about telpherage, but the above will give a general idea of its work. Many plants have been installed and many more are being installed daily, and in many instances duplicate orders are being received from former customers.

Discussion.

President Steinmetz:—Gentlemen, you have heard a paper, which, while relatively short, has brought before you a very large amount of material for further consideration and discussion. The showing made by the alternating current motor in this paper is so disastrous that I hope some of the advocates of the alternating current will take up the matter as soon as they are ready for discussion and defend the alternating current in this respect. I might say one thing, however, in its defence. I think it is not quite fair to mass all the alternating current motors. I wish that Mr. Sever had separated the rheostatically controlled motor from the motor with no controller, and had shown us the current of this motor in starting, because there are two essentially different types of induction motor; the rheostatic motor and the motor with no controller. The former motor is essentially a high torque acceleration motor and would be the motor eminently fitted to be chosen for elevator service as far as feasible. This motor should give results closer to those derived from the continuous current motor than the motor without any controller, which, I am sorry to say, has been most generally installed here, giving poor starting torque and large starting current. While Mr. Sever mentions that the rheostatically controlled motor starts more slowly—that is not necessarily the case. In the rheostatic motor a small starting current may be allowed by limiting the starting torque. Larger torque may be obtained by increase of current. There is one point which appears to be rather high, the power factor in starting. I would not have expected a 60-cycle motor to give any power factor like that, especially one of 97 per cent., which is certainly a good deal higher than anything I have heard of for 60-cycle induction motors. The next paper on the program is by Mr. Charles M. Clark on "Telpherage." Mr. Clark, unfortunately, could not be here, and Mr. Burnett has kindly agreed to read the paper in abstract.

[Mr. Clark's paper was then read by Mr. Burnett. See page 435.

President Steinmetz:—Gentlemen, you have listened to the second paper, on "Telpherage," discussing another problem, in this case horizontal propulsion; not, however, with a car running on a track, but with a vehicle suspended from a track, a wire rope. Discussion is now in order. I will call first on Mr. Ihlder to give us his views on the electric elevator question, with which I know he is very familiar.

Mr. John D. Ihlder:—I beg to call your attention to the fact that Curve 4 refers to a direct current machine of 110 volts. This fact is stated in the paper, but in small print which is apt to be overlooked, especially since all the other data is for 220-volt machines.

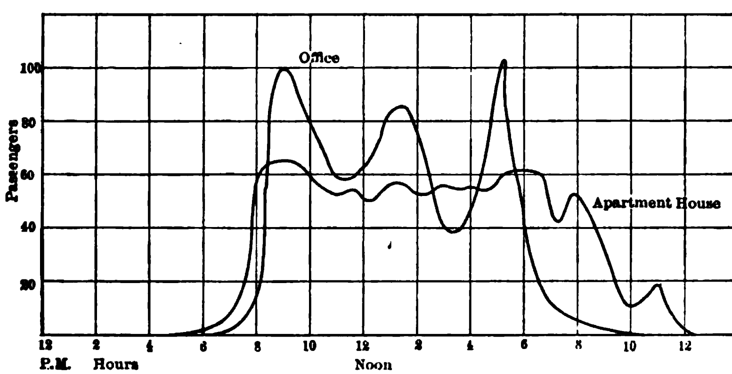
The information presented in this paper treats the subject only from the standpoint of power consumption, which in elevator service is really of minor importance. The most essential requirements of elevators are safety and good operation, and in both these respects the elevator operated by alternating current is inferior to the elevator operated by direct current, because the alternating current motor is fundamentally a single-speed motor, since variation of speed by resistance is not permissible in elevator service where the descending load frequently changes the motor into a generator, while the direct current motor speed may be varied positively over wide ranges; and the stop, the most important factor of all, may be made to perfection with the direct current motor, while the alternating current motor requires that the machine be stopped by means of the mechanical brake only. This becomes very objectionable for higher speeds and the consequence is that no high-speed alternating current elevators are in operation. You will notice that the highest speed quoted in the paper is 180 feet.

The present state of the art is thus preponderatingly on the side of the direct current motor for elevator service; whether the alternating current motor may be developed to equal its rival must be left to the future.

MR. A. V. ABBOTT:—Mr. President and Gentlemen: It appears to me that the INSTITUTE and particularly those of us who are engineers in consulting practice are much indebted to Mr. Sever for additional information. We all know that one of the most important problems at present is to obtain a good day-load for central stations and the motor is the thing to which we direct attention more than anything else. Elevator motor work appears to be one of the most promising fields which the central station manager can cultivate. Look a moment at the immense number of apartment houses that are springing up in all of the modern cities; in New York for example, I can remember, and I am not as old as some persons here, when there was not an apartment house in the city, and now there are thousands. At first they were only a few stories high, now they average a dozen or more, and some means of transit between stories must be provided; there is no question about that, and so the best means to employ in propelling the elevator car becomes a serious and far-reaching problem and one to which the central station manager may well afford to devote plenty of attention.

It appears to me that the elevator problem may be divided into two parts, in much the same way as the street railway problem. We have the city car which is expected to stop at every block to take on passengers and must have a rapid acceleration, not so very high speed between stations, but must start and stop readily and quickly. Again, there is the interurban service in which the cars are larger and heavier, and run longer between stations, and in which the acceleration need not be so great, but the running speed much faster. Now it appears that the elevator problem is of the same nature. In the office buildings in the business districts of large cities there are two kinds of elevators, an express elevator, which rarely stops below the twelfth floor, and the way elevator. These two machines are called on for totally different services, as different as those of the interurban car and the city car, and it appears to me that they must be dealt with from different points of view. The express elevator carries large loads and makes a comparatively small number of stops; whereas the way elevator carries smaller loads and makes many stops. The apartment house elevator is usually of the way type and rarely is an express elevator.

I think that the load line of elevator service is well worthy of study and consideration. Two or three years ago I had occasion to deal with an elevator problem of some magnitude involving the consideration of a possible change from hydraulic elevators to the electric service. It was found that the elevator load line would be somewhat as I will show you on the blackboard. Suppose the horizontal axis to be a 24-hour line and the vertical one to represent passengers. There is but a very small load after 7



P.M., and before 8 A.M., but soon after 8 o'clock the number of runs increases rapidly, then drops from 10 to 11 o'clock. There is a peak between 12 and 2, then another peak between 4 and 6. That is a rough diagram of what is to be expected from the ordinary office elevator. In an apartment house the load line is totally different. The load starts at least an hour and a half earlier, runs up very sharply, but remains much steadier during the whole day. There is another peak in the evening, due to the theatre load social calls, and things of that kind. But those load-lines from the standpoint of the designer of machinery to handle elevators, are worth serious and careful consideration. In the office the peaks are sharp, very abrupt, whereas in the apartment the load is relatively much steadier, giving a much broader diagram with fewer peaks. In the office building the load line is more nearly constant from day to day owing to discipline. The large office buildings arrange their elevators to make regular and systematic trips. They have, perhaps, half a dozen elevators; at least two or three are in constant service all the time, so that the total load line of the building is nearly a constant one, with the peaks of the morning, noon and evening loads superimposed thereon. In the apartment house, on the other hand, the elevator runs on call. It is by no means so constant or so steady a load as in the office building. This point was well brought out in a paper by Mr. B. J. Arnold before the INSTITUTE, some years ago, in which he described a storage battery plant, which he had installed in the Board of Trade building in Chicago. The point that I want to emphasize particularly is the difference in the load lines between the two classes of service. Now that Mr. Sever has broken the ice and has done some missionary work, for which I personally am very much indebted to him, in opening this subject, I think we would all be the more indebted to him if he would go one step further and give us some information with regard to the load lines of the elevators, which he has examined. It appears to me that Mr. Sever is undoubtedly right in calling attention to the fact that too great attention is paid in the apartment house elevator to rapid acceleration. There is no need of it. People do not want it. They do not like it, especially ladies. They do not wish to be jerked up by the root, so to speak, and hurried through the air. The acceleration should be much more easy. Dwellers in an apartment house are not like business men in an office building; they are not in a hurry to get to the 29th floor in three seconds less than no time, but they are willing to go a little more slowly. A man after he finishes breakfast in the morning is not in such a great hurry to get to the office. So that for apartment house work I feel quite confident that a much lower rate of acceleration would prove equally satisfactory and, in many cases, much more agreeable.

In the last paragraph Mr. Sever calls attention to the fact that while the alternating current motor shows on examination a larger expenditure of power, the questions of convenience and of maintenance are important, and I am sure that we would all feel very grateful for additional information upon this point. There are very many cases where we pay more, from the standpoint of power consumption, for the sake of convenience. In fact, I think that a very large proportion of the success of electrical industries has been due to the question of convenience. For example, I have no doubt that we could light this room more cheaply with Welsbach lights than we light it with incandescent electric lights, but we do not. Now the case of an alternating current motor presents one point of peculiar interest in this connection. The average apartment house is not equipped with a skilled engineer. There is an engineer, so-called, but he is very often fireman as well, and in many cases has been promoted from the rank of fireman in an office building downtown, and, while he has a general idea of engines and machinery and can pack a steam gland under stress of circumstances, and possibly patch up a leaky joint in a water-pipe, he knows very little about electrical machinery as such, and the more we can avoid complication in all forms of machinery, which are to be placed under the charge of such a man, the better it is. I venture to say that in the average apartment house the actual expense of running the house for a year would be less with an alternating current motor than it would be with a direct current motor; there would be fewer repairs, less time when the commutators were out of order, fewer broken brushes, etc. We ought to take into consideration not simply the question of cost of power—that is an engineering question—but also consider the kind of attention which the elevator is likely to have.

Apartment house elevators are usually put in the charge of a boy who is anything but an electrical expert, and under these circumstances the machine must run itself. It must operate when it is covered with dust and dirt, when the cellar is flooded, and under all sorts of circumstances, often as bad as those to which the early electric street cars were subjected, when they often ran with brushes half under water. What the owner of an apartment house wants is not simply to know that at the end of the year he has paid for a few kilowatts less, but that his building is a success as a whole, has given him no trouble and his tenants have not complained, and the elevator service has been satisfactory. He does not care particularly for a few kilowatts one way or the other. I think that if we could obtain some information that would show us that the alternating current motor—if that should be the case—was on the whole cheaper when one came to take into consideration cost of repairs, regularity of service and satisfaction to consumers, it would be very valuable.

The President a few moments ago alluded to the use of hydraulic elevators. It is probably true that the hydraulic elevator has been the most successful form of elevator used. But, as Mr. Steinmetz stated, it is a horribly inefficient machine. It takes a whole cylinder of water every time, whether it takes one passenger or an elevator full. Hydraulic elevators are usually arranged so that the descent is managed by allowing the water from the upper side of the piston to flow in on the under side, thus acting as a brake and not necessarily consuming any additional water for the down trip. But, on the other hand, there is no means that I am aware of by which that efficiency may be improved. Inasmuch as the whole cylinder must be filled at every trip, there must be either two reservoirs at different levels or some form of reducing valve to decrease the pressure of the water, or else an equal number of foot-pounds of water will be used whether the elevator is full or empty. So far as I am aware, there are no commercial devices on the market at the present time for improving the efficiency of the hydraulic system. The use of an electric motor for pumping water has been suggested in order to put a steady load upon the motor that supplies power by having a sufficient tank on the top of the building, so that the peaks of the loads could be carried by the reserved water in the tank, and the pump with its motor could operate practically continuously and under nearly a steady load. In one case I had occasion to remodel some hydraulic elevators and substitute electrically driven pumps for steam pumps, and on the whole in that instance a considerable economy was shown, for the reason that in the ordinary direct-acting steam pump the piston speed is slow, and there is no means of expansion, so the steam consumption is very great. An electric pump driven by a generator operated from a large engine, showed a considerable economy in actual steam consumption and, in that instance, a decided saving.

MR. PHILIPPO TORCHIO:—I think that if we can find any fault with Mr. Sever's paper, it is that he has compared the direct current elevator, which is well developed, with the alternating current elevator which is not fully developed. The comparison would have been more interesting if he had made it on the basis of what the best type of alternating current elevator could do. I was aware that the alternating current elevator used more energy than the direct current elevator, but I am surprised to see that the difference is so large. I want, however, to ask the author how he explains the fact that an alternating current elevator going up takes 50 per cent. more energy than the direct current elevator, and the same elevator coming down takes only 8 per cent. more than the direct current elevator. I do not see clearly why such a difference should exist, unless the elevator tested was designed on considerably different mechanical principles.

PRESIDENT STEINMETZ:—Discussion is still in order and we would all like to hear from Mr. Mershon, who has undoubtedly had considerable experience in the matter.

MR. RALPH D. MERSHON:—Mr. President and Gentlemen of the INSTITUTE: It seems to me that this paper would be more valuable if a little more information were given in connection with it. For instance, in the first table there are a number of things which are not quite clear. One column is headed "duty in pounds." As this paper was prepared with reference to the duty of the motor, that might be taken as the effective weight against which the motor had to work. Again, it might be taken as the load which the elevator is supposed to carry. We have in the next column, "overweight in pounds." Does that mean counterweight or does it mean the difference between the weight of the cage and the counterweight? It seems to me, also, that we might have had a little more information as to the type of motor used. I presume that with direct current it was always a series motor. And we should also have information as to the type and method of control.

There is another point which has already been mentioned, namely, the power factors given for the alternating current motor. They are surprisingly high for the motors on which they were taken—motors without rheostatic control. I do not believe I have ever known of an elevator motor giving as high a power factor as these are shown to have given at starting. The design of variable speed alternating current motors with variable voltage control is not such as to give a high power factor at starting. The fixed resistance in the secondary is necessarily a compromise between that best suited for running and that best for starting, and it is not that resistance which gives the highest power factor in starting. There was a statement made that the starting orque with a motor having voltage control was necessarily higher, as I understood it, than one having rheostatic control. This is not the case, as a higher starting torque can be obtained with a motor having rheostatic control—quite considerably higher in most cases.

The comparison here has mostly been made between the direct current motor and the induction motor with voltage control. As has been said by one or two others, this is hardly a fair comparison, if we are going to make a general comparison of the direct current motor and the alternating current motor. It may be a fair comparison as between motors which were found actually installed, but the type of alternating current motor of which, for the most part, this paper treats, is the very worst that could be used for elevator work. The last motor given in the table represents the type which ought to be used in all cases and which would give a better result as compared with the direct current motor. The direct current series motor will from the inherent qualities of the motor itself always take less power than an alternating current motor as now built. I say as now built, because I think it is possible to build an alternating current motor which would take no more, and probably less power, than a direct current motor. However, they are not available to-day. The discrepancy between the two motors would not be nearly so great if the comparison were made between the direct current series motor and the alternating current motor with rheostatic control. While the series motor has the advantage as regards the actual amount of power used, it has not necessarily the advantage as regards ultimate economy because we must consider under the question of economy not simply the power used by the motor, but the performance of the motor with respect to the whole system on which it is used. The total number of motors connected in New York City, that is, both constant speed and variable speed, constitutes about 45 per cent. of the total amount of apparatus connected. About half of these motors are variable speed motors. The ultimate question in a case like this would be not as to the relative amounts of power required by direct and alternating motors, but by means of which kind of motor could service be more cheaply rendered: whether for a variable speed motor service which constitutes 22½ per cent. of the total apparatus connected, it is cheaper to provide a means of supplying direct current, or to use for this service a motor somewhat less efficient and by so doing make possible the serving of all the apparatus of the system from alternating current mains. I think that in most cases the use of the alternating current motor for this work will be amply justified by the cheapening which will ensue in the cost of the service as a whole, due to the fact that it is then possible to supply all kinds of service from the same mains without the intervention of a rotary converter and the expense incident thereto.

There is another point also which we must consider in the question of economy, and which has been raised by some of the others who have preceded me. That is the question of the hardiness of the motor itself. I think there is no question but that the alternating current motor will take the palm on this score.

There was one statement made in regard to acceleration with which I cannot agree, and that was that the economy will be higher with lower acceleration. I think that is not the case. The economy will be higher the higher the acceleration, as far as the power taken by the motor is concerned. Consider a shunt motor controlled by a rheostat in the armature circuit. Part of the current which flows at starting is that for the torque necessary to overcome friction, and part is for the torque necessary to produce acceleration. Now, the latter is greater, the greater the acceleration, and the kilowatts in the series rheostat is greater for greater acceleration. But greater acceleration in attaining a given ultimate velocity means that the current for producing it lasts for a shorter time and *vice versa*, the relation between current and time being such that the kilowatt hours expended upon the rheostat and due to that portion of the starting current necessary for acceleration is the same, no matter what the time taken to accelerate to a given speed, and is always equal (disregarding efficiencies) to the energy stored in the mass accelerated. That part of the starting current necessary for the friction torque is the same no matter what the acceleration; therefore, the kilowatt hours lost, due to this part of the current are proportional to the time taken to accelerate. It follows, therefore, that if we accelerate quickly, while we shall not alter the kilowatt hours lost, due to the acceleration current, we shall lose less kilowatt hours due to the friction torque current. If there were no friction load it would make no difference whether we accelerated in a long or short time; the kilowatt hours lost in the rheostat would be the same, and always equal to the energy stored in the mass accelerated; while with friction present, the sooner we get the mass up to speed and the friction load current out of the series rheostat, the fewer will be the kilowatt hours lost in the rheostat.

I might say, simply as a matter of interest, that the statement just made for a shunt motor under rheostatic control as regards the relative loss with quick and slow acceleration holds for a friction clutch running at constant speed, and used to accelerate a mass and at the same time carry a friction or other steady load. The statements made for a shunt motor will hold for an induction motor under either rheostatic or voltage control and will hold qualitatively, though not quantitatively, for a series motor.

The point made in regard to the headings of the two columns —data in pounds and overweight in pounds—has another bearing, and that is this, that the power taken in starting is going to depend on the total mass involved, and without knowing this mass one cannot make an intelligent comparison of the different readings given. Certain curves have been plotted by having the energy in kilowatt seconds for 50 feet rise for a certain number of passengers. That might be very different in two elevators, and while the points shown on these curves seem to come pretty well on the curves, so that the masses involved in the different cases were perhaps somewhere nearly the same, the measurement would be very much more valuable if the masses were given, so that one could analyze the measurements and make a close comparison of the different ones taken. I think also, as mentioned by our President, it would have been very much more interesting if we had some of these curves on an alternating motor having rheostatic control.

PRESIDENT STEINMETZ:—Gentlemen, perhaps Mr. Sever can answer a few of the questions raised here regarding the type of continuous motors used, whether series or shunt, and the system on which they were operated, and approximately, what proportion of them were operated direct from electric lighting mains, what from isolated plants, what from separate generators with rheostats reducing voltage and transforming devices.

MR. SEVER:—Mr. President, I can give you some of the information, but I have not all of it immediately at hand.

Taking up some of these points, perhaps a little out of order, Mr. Mershon asked as to the duty and the overweight. Regarding the headings which appear in Table 1, the "duty in pounds," is the weight which the motor is designed to lift. The motor when operating at full load will lift that number of pounds if placed upon the car. The "overweight" is the number of pounds which overbalances the weight of the car. In tests from 1 to 5, as I remember the conditions, compound motors were used, that is, a direct current motor with a shunt and a series winding, the series ampere turns, acting in the same direction as the shunt ampere turns. The method of control in test No. 1 at the Horace Mann School, direct current motor, was that of the Otis Company, known as the magnet control, that is, a magnet which actuates a rheostat arm throwing the current onto the motor and gradually cutting out the resistance in circuit. Test No. 2 at the Mason & Hamlin building was of an A. B. See elevator using a magnet control. Mr. See is here to-night and I think he can explain that test much more fully than I can.

Test No. 3 was at the S. Stein & Co.'s building and was of an Otis elevator with one of that company's motors, which was regulated by hand, that is, a wheel in the car regulated the resistance in the armature of the motor.

Test No. 4 was of an Otis elevator with an Otis motor using magnet control of that company's style 67, this being somewhat similar to the other type.

The Bryant Park Studio building has an A. B. See elevator with an A. B. See motor, using magnet control similar to the other.

The further tests Nos. 6, 7, 8, 9, 10 and 11 were of alternating motors using, in the last two cases, two different types of control, and in the first four cases simply the switch throwing the current onto the motor. In the presentation of the paper, except unfortunately in one case, I have carefully avoided mentioning the types of elevators and motors. I understand that it is against the desire of the Committee on Papers and Meetings to make such mention, but as the request has been made, I will give these additional details:

Test No. 6 was of an A. B. See elevator with a No. 3 type C, Westinghouse two-phase motor, with no control.

Test No. 7 was of a National elevator, type C, Westinghouse No. 8 motor, two-phase, sixty cycles.

Test No. 8 was of a Reedy elevator, type C, Westinghouse No. 2 motor.

Test No. 9 was of an A. B. See elevator, type C, Westinghouse No. 8 motor.

Test No. 10 was of a McAdams & Cortwright elevator, type C, Westinghouse, No. 2 motor.

Test No. 11 was of an A. B. See elevator, No. 15, type F, Westinghouse motor. The type of control in test No. 10 involved the use of two transformers, one giving 60 volts for starting, and the second giving 175 volts for running, the motor being started first on 60 volts, and after getting up to speed being operated on 175. (When this was operated more carefully by the students who were making the test than it was by the regular operator of the elevator, the currents were considerably reduced). In the last test, No. 11, the elevator was operated with resistance in the rotor, giving small starting currents, and having four points on the control.

I will admit that the power factors on starting are high, but it was very difficult to get instantaneous readings of the current and the voltage on these motors with the alternating current instruments, using a wattmeter, an ammeter and a voltmeter. The alternating current instruments were not dead-beat. Numerous trials and readings were made and the results are correct as nearly as possible, but I will admit that a 97 per cent. power factor is a little excessive. It was quite a difficult proposition to get instruments, or to make the instruments read satisfactorily with the tremendous variations in the current. It was necessary to employ two ammeters, so arranged that the large reading instrument could be used in starting and the small one could be immediately cut in to ascertain the running value of the current. The suggestion has been made by Mr. Mershon that further comparison should be made and more definite data presented for the different machines. We have all that data and I would like to follow his suggestion and present it as a supplement to this paper in the form of a communication.

I will take exception to the remark of Mr. Abbott to the effect that the direct current motor is a machine that you can injure easily, that is, the present day direct current motor. On the contrary, it is a very hardy machine. As an instance of that, I have in my laboratory an Eickemeyer motor which was presented to us about ten years ago.

PRESIDENT STEINMETZ:—More than ten years ago.

MR. SEVER:—I know that it was two or three years before I went to Columbia and that is about ten years ago, so it must be twelve or thirteen years ago. That motor has been in the hands of over three hundred students in the junior class, and it is one of the finest operating motors that we have in the laboratory. It still has the old brushes that came with the motor and the old commutator, which has simply been sand-papered, and is in just as good condition to-day as when I first saw it when I went to Columbia University, and it has not received particularly good care. As an example of an elevator motor, I think this is an excellent one. My experience with Eickemeyer motors in the shape of railway motors was not quite so pleasant. I had the pleasure of putting in, I think, a dozen of them on a road in my early days in New York City, after having taken instruction from Mr. Ihlder at Yonkers, but I needed further instruction.

I was interested in Mr. Abbott's remarks on express and way elevators which are used in office buildings, but I understand that there is some question as to the advisability of running express elevators. I think there is a certain height of building in which their use may be economical and advisable. Below that height it does not pay to operate them. I would be very glad to hear more on that subject, and I should appreciate it very much, Mr. President, if we could have Mr. See's views on this matter, because I am sure he can give us valuable information.

PRESIDENT STEINMETZ:—We should be glad to hear from Mr. See, but before that there is a question which I think you have not answered—how far the elevators were operated directly from electric lighting mains, whether intermediary motors were used to supply the voltage, or whether they were operated on separate systems, especially with reference to the continuous current motor, because the alternating motors could be operated from the 60-cycle system.

MR. SEVER:—I am afraid that I will have to call upon one of the gentlemen who made the test, Mr. Rosenblatt, to give us that information.

MR. ROSENBLATT:—The only elevator that was operated on an isolated plant was the first one. We had a 110-volt circuit in that case for house lighting, on which the elevator was run. All the other elevators were operated from the street circuit, 240 volts supposedly.

PRESIDENT STEINMETZ:—Was any intermediary apparatus used?

MR. ROSENBLATT:—Nothing in between.

PRESIDENT STEINMETZ:—Mr. See, we should like very much to hear from you.

MR. A. B. SEE:—As engineers, it is proper that we should take up this question of the relative durability of the alternating and the direct current motor for elevator service. Practically, both with the direct current and alternating current, elevator motors are very durable. Plenty of elevators of both types are running here and scarcely any repairs are necessary. Consequently, I think there is very little difference in that respect to the man who is purchasing an elevator.

As for the motor itself, we use a shunt-wound motor with some series turns, and I think that almost everybody uses the same—not a series motor, but purely a shunt motor, with some series turns to help in starting and the shunt to give steady motion. I think that the excess current in starting the alternating machine is due in a great degree to the large armature. In a direct current machine it is possible to have a smaller armature, but in the alternating current motor there is a very large armature, and a great deal more current is required to start that heavy armature than is the case with the direct current motor.

MR. ARTHUR WILLIAMS:—Mr. President, I am very sorry that Mr. Sever's paper shows this large difference in favor of the direct current electric elevator as compared with the alternating current elevator. I have been hoping that the advocates of the alternating current would make a better presentation of their side, showing either that the tests were incorrectly made, or at least that there was some hope of obtaining better comparative results in the future. We certainly want good and efficient motors and elevators of both types.

Curiously, the conditions in practice are exactly the reverse of the theories outlined by a former speaker. On any large system with which I am acquainted, even the largest elevators are supplied directly from the street mains supplying the lighting installations; with very few exceptions the same service will even supply both light and elevator power, and any other power that may be desired, all to an unlimited extent. In the Transit building, to which reference has been made in Mr. Sever's paper, one service is sufficient for all needs. A second service, however, is usually placed in buildings of this nature, to remove any possibility, however slight, of interruption to the service. On the other hand, I think I am safe in saying that it is the practice on alternating current systems to supply elevators and other large power installations from a separate and independent secondary network.

It is true also, I think, that contrary, to the usual expectation and the suggestions of one of the speakers, the alternating current elevator is more costly in repairs, as well as less economical as regards the current required for its operation. These conditions may seem anomalous, but nevertheless, in the opinion of the operators and the users of the two systems, even additional advantages lie with the direct current—such as higher speed, better control, and entire freedom from noise, either from the motor or the apparatus controlling it.

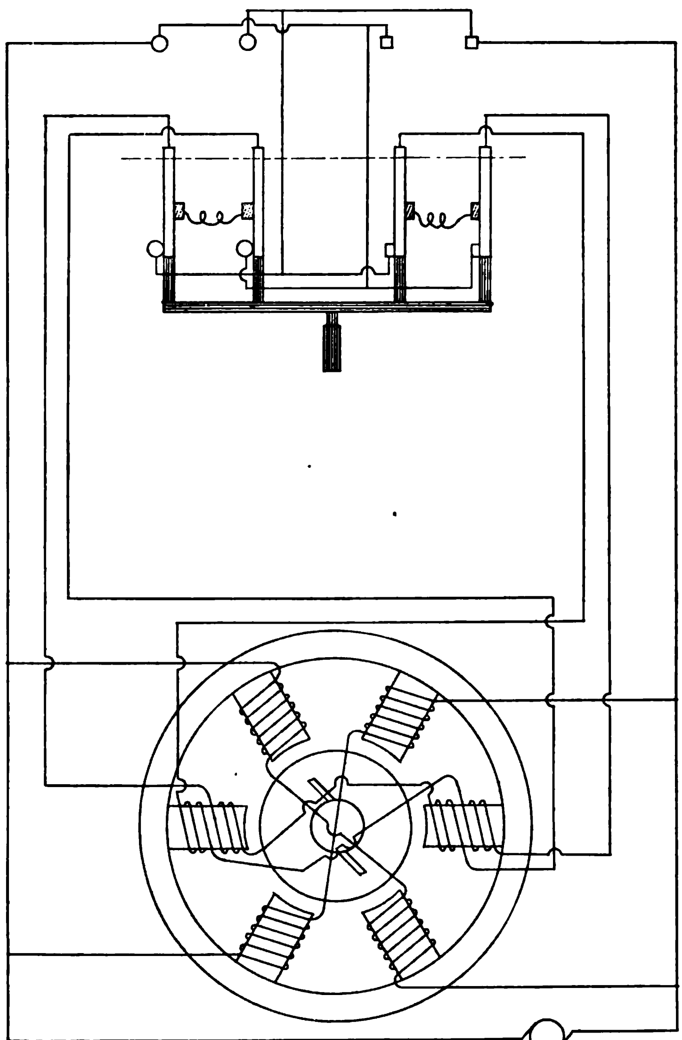
The members present may be interested in knowing in a general way the power requirements of electric elevators of the two types under discussion. Operating with direct current, the direct-connected drum type of elevator with a worm gear—the type in most general use—will consume from 2½ to 3½ kilowatt hours per car mile. When supplied with alternating current for the same work, the current requirements are perhaps a third more. These machines operate within the limits of current consumption which I have given at speeds of from 200 to 350 feet a minute. Elevators of higher speeds, up to 650 feet a minute, which have thus far been equipped exclusively with direct current apparatus, consume from 5½ to 6½ kilowatt hours per car mile, and the electro-hydraulic elevator increases the consumption of current as much as 10 or 12 kilowatt hours a car mile.

In spite of the higher power consumption of the latter type, its use may be found profitable where it is possible to abandon high-pressure steam service and a special engineering staff, because here we have the immediate cost of operating the elevator, in comparison with the unquestionably larger expense of a steam plant maintained solely for that purpose. I think, however, that had the investigation been carried a degree further, the complete substitution of electric apparatus with a direct connected motor would have been found much more economical.

Notwithstanding the little that has been said to-night on behalf of the alternating current elevator and motor, it is a matter of great satisfaction to know that in the more recent types, such, I think, as type " F " of the Westinghouse Company, and types representing corresponding developments of the General Electric and other companies, the results have been much more satisfactory; so that while with motors of former designs it was practically impossible to give elevator service from the systems of the outlying districts, the new types are giving results which enable this service to be given readily and without undue cost, either to the supplying company for a larger distributing system, or to the consumer for an excessive amount of current from which he gets no direct benefit.

MR. EDWARD P. THOMPSON:—We are certainly greatly indebted to the author and his assistants for making these exhaustive tests. I am perhaps among the few to whom it is immaterial whether the alternating current motor or the direct current is ahead in this matter. I think he has shown pretty conclusively as far as he has gone, that as far as the power consumption is concerned, the direct current is probably more economical;

but, of course, as the general view of the members present seems to be that we have to consider which is preferable, I want to speak briefly about a matter alluded to by several speakers in reference to direct current motors, that they involve rheostat



regulation and are therefore objectionable. It reminds me of a case with which I was connected some time ago, involving some investigations by Prof. Anthony. I will give the features of his motor for elevators. It seems to obtain all the essential results of the proper motor for running elevators, for getting the rapid acceleration and for preventing any jerk or shock to the passengers. The broadest claims were allowed by the Patent Office, thereby indicating that I am not talking about something that does not belong to Prof. Anthony. The principle is illustrated in the diagram.

His experiments related mainly to means for regulating electric motors, and particularly to a regulator for multipolar direct current electric motors. The use of the motor is not limited to any particular purpose, but belongs especially to that class conveniently employed in running elevators, hoisting machines, street-cars, or machinery, the speed of which frequently varies from zero to maximum.

The system involves such multipolar machines as have an odd number of pairs of poles, as six, ten, fourteen poles, etc., since in such machines poles diametrically opposite each other have opposite polarities, and two such poles may be taken as a pair, the magnetic strength of which is to be varied. By so doing, the magnetic attraction on opposite sides of the axis may be maintained in perfect balance at all times, whatever variation may be made in the field-magnet strength for the purpose of varying the speed.

In applying the invention one or more pairs of magnet-coils are cut out in succession, or a pair of coils may be cut out and then cut in again with the connections reversed, thereby reversing the current through the coils. The coils may be cut out as a whole at one operation, or they may be divided into sections, the separate sections being cut out in succession as occasion may require.

The novel conception underlying the motor is the method of operating a multipolar electric motor having an odd number of pairs of poles. This method consists in varying the total electromotive force of the armature by varying the magnetic strength of one or more of the pairs of the field-magnet poles.

Under his demonstration any construction falls that consists of a multipolar motor and means for varying the strength of any pair, or pairs, of field-magnet poles.

Of course it is an old idea to sub-divide field windings and to cut in and cut out field coils, but the practical success of this motor is due to balancing the magnetic attractions on opposite sides of the armature at each degree of regulation.

MR. PHILIPPO TORCHIO:—A gentleman was telling me to-night that some engineer out West called on a manufacturer for some street railway motors and wanted the motors having low acceleration. The manufacturer asked him why he did not ask for rapid acceleration motors and the explanation given was that the conditions there were peculiar as the road was almost always on a level and whenever it was different it was always down.

Now, Mr. Sever has not yet answered my question as to why on going down he has such an efficient alternating current motor, and going up so inefficient a motor. I would like to hear from him.

MR. MERSHON:—There is a question which I would like to ask Mr. Sever, his answer to which I did not understand before, that is, in regard to the "overweight." I do not understand yet whether that is the counterweight or the excess of the counterweight over the cage.

MR. F. V. HENSHAW:—Since we are asking Mr. Sever for information, I would suggest that he state the acceleration of the elevators described in his paper. It would appear on the face of it, that the acceleration, or period from rest to full speed, was the same in all the elevators tested, but I doubt whether that was the case. Of course that has an enormous influence on the amount of starting current. I would draw attention to the fact that we have discussed thus far the total power required to operate elevators; that is, the power required in kilowatt hours. Now, what is generally of more importance than that (although I must say I have not found many cases of that indifference to meter bills to which Mr. Abbott referred), is the maximum inrush of current at starting, particularly if there is electric lighting on the same mains which supply the elevator motor. A type of motor which does not permit of materially reducing the maximum starting current is not likely to be a very successful elevator motor. The direct current elevator motor is almost universally compound-wound, usually with a great deal of compounding and comparatively little shunt. The speaker who stated a few minutes ago that shunt motors were largely used in elevator work was mistaken. Some of these compound elevator motors work up to 20,000 or 30,000 ampere turns on fields at starting, producing enormously high saturation of the magnetic circuit and they naturally produce a very powerful torque with comparatively little current. I think on account of this low starting current feature that when two sources of electric supply were at hand, one alternating and the other direct, no engineer would hesitate very long as to which he would select for an elevator motor. There is no indication at present that the alternating current motor can be re-designed to accomplish results similar to those obtained by the direct current motor in this class of work.

In regard to Mr. Mershon's view that in discussing the elevator problem the relation of the motor to the system must be considered, it hardly seems to me that this is pertinent to the present discussion. It seems that we cannot discuss the uses of alternating current motors without taking in the whole system. The moment we take any liberties with an alternating current motor, we are liable to mix up the system. The point, however, that I wish to make is that the amount of power required for elevators operated from central stations is hardly sufficient to have a serious influence in determining the method of transmission to be employed. Even if the alternating current motor could be so altered as to make it perfectly adapted to elevator work, I hardly think that this one adaptation would result in the general adoption of the alternating current distribution in large cities.

PRESIDENT STEINMETZ:—Gentlemen, as regards this inrush of current, I may say that it is indeed a serious matter, especially where there is not a system of unlimited power behind to draw upon. I believe that Mr. Ihlder can tell you something of his experience in the early days when trying to install an elevator motor, in getting the consent of the central station to supply the starting current. Indeed, the alternating current motor is a specially vicious offender in that respect. Perhaps we do not need to blame the motor so much for that. But most continuous current motors involve such an inrush of current that for designing reasons we have to limit it, while this is not essential in the alternating current motor. However, there remains one feature—it is not so much the greater power required by the alternating current motor that is such a disadvantage in elevator service and in a very large part of intermittent service. We really do not care so much for power as for reliability. An alternating current motor is essentially a constant speed motor. It is just as much a constant speed motor as is the continuous current shunt motor. It may be made to run at lower speed by throwing away the power corresponding to the difference between its synchronous speed and that at which it actually runs. The continuous current motor is a variable speed motor. There is no doubt again that the alternating motor *per se* is a more reliable one—simpler in construction—and at the same time we must consider that any apparatus is most reliable and satisfactory and least exposed to damage, when it is run in its proper field of operation. If an alternating current motor, no matter how reliable it is by its inherent construction, is put in an acceleration service, it is probably not as reliable as the continuous current motor, which is probably particularly fitted for that service. That is probably the reason why experience shows that alternating current motors give more trouble in repair than continuous current motors in this particular class of service. At the same time we must consider also that the alternating current elevator motor is not developed yet to anything like the same extent as is the continuous current motor. However, I believe that the question is not whether alternating or continuous current motors are preferable for elevator service at present, because most engineers who have studied that matter will say that they prefer a continuous current motor always when continuous current is obtainable, and where they cannot get continuous current, then the alternating current may be used, and used successfully. They say, too, that it will be still further developed so as to approach still more closely the good features of continuous current motors as used in this particular class of service.

MR. MERSHON:—I agree with Mr. Henshaw that we ought to hear something in regard to acceleration. I disagree with him, however, in the statement that the station has nothing to do with the question under discussion. It has a good deal to do with it, it seems to me. Suppose you had a plant in which the major portion of the load was lighting and constant speed motors, and with a certain number of elevators to serve. Would you serve them by means of alternating or direct current motors? If by direct current motors, it means that the system must be a direct current system, either in whole or part, instead of all kinds of service from one set of alternating mains. This would involve also the installation of the additional apparatus which will have to be taken care of in order to serve them, whereas, if they were served from the alternating current mains, they would be supplied from the same apparatus that supplied the rest of the load.

MR. HENSHAW:—Perhaps Mr. Mershon misunderstood me. I appreciate fully the force of his remarks, but I think the elevator motor is not a very large factor in determining the method of distribution, being a small proportion of the total load. I think that the paper before us deals with a concrete case of the elevator and its driving motor which can be considered by itself.

MR. MERSHON:—If you let it go at that you leave a very wrong impression, I think. Then the amount of power involved in each case is the all-important thing and represents the relative cost of operation. You leave a very wrong impression as to the cost of operation in ordinary lighting systems.

PRESIDENT STEINMETZ:—I believe that the elevator motor in large cities is of considerable importance in considering the system: From the figures in Mr. Sever's paper, we see that there are about 3,000 elevators operated in New York City. We assume that they are operated at an average of 10 horse power; that amounts to 33,000 horse power of motors installed in New York City alone. I think Mr. Henshaw can give us some information in regard to how important a part of the service the elevator motor represents.

MR. HENSHAW:—I would point out that we do not know how many of these motors are operated from central stations.

MR. TORCHIO:—I think that the subject of the best system of distribution in a city is not involved in the consideration of this paper. I might state, however, that the direct current elevator is a great factor in a large city. For instance, private plants use almost exclusively direct current and direct current elevators. To supply this large class of customers with central station service, the company must be in a position to run their elevators. So the selection of the system of distribution is of great importance. This question was brought out very strongly by Mr. Ferguson, of Chicago, a few months ago before this INSTITUTE. I have only to refer to the discussion of that evening for further information on this subject.

MR. IHLDER:—The question of starting current in elevator work is quite important. We always specify the amount of in-rush current which the power circuit must be ready to furnish for a given elevator and our experience is that there is no trouble on direct current circuits, but on alternating current circuits we frequently are in difficulties, even after the power company has given us the assurance that it is prepared to furnish the amount of current specified.

Regarding the question of robustness of direct current and alternating current motors, it is stated that the alternating current motor requires no starting apparatus and is consequently much simpler, but this is only true when the alternating current motor of highest starting current is used. As soon as the starting current has to be reduced, a rheostatic control must be added and the only remaining difference then is that the direct current motor has a commutator which is replaced on the alternating motor by slide-rings.

About those peaks of power consumption especially in apartment houses, I would suggest that these could be readily made unobjectionable if the size of machine installed were reduced. The usual practice is to install cars and machines for the maximum duty which may be called for a few times per day, probably because the owner believes that the tenants are in a hurry and object to waiting even if only once in a long while.

MR. H. G. STOTT:—I remember one particular case in which a hydraulic elevator, receiving its pressure from an electrically driven pump, cost so much for power that the owners threatened to throw it out. We, however, recommended that an automatic regulating device, which was controlled by the hydraulic pressure, and which automatically started and stopped the motor, should be installed. This was done with a resultant saving in their power bill of about 66 per cent. Without automatic starting devices such as above mentioned, it has been my experience that it is impossible to hold a customer. It has also been my experience that much more reliable service was obtained from the hydraulic-electric driven combination than from the direct electric. We had no A. C. motors in use for elevators.

MR. DOUGLASS BURNETT:—Mr. President, the three gentlemen who have referred to the question of adapting hydraulic elevators to electrical operation have proposed a compromise. They have inferred, while not directly stating it, that existing elevators of this type should continue to be operated by the hydraulic method; substituting, however, the steam-driven, by an electric motor-driven pump. I think the position of the INSTITUTE should be that the direct-geared electric elevator is capable of meeting any building conditions; and that it should be, and is, the sense of this body that the electric elevator is not excelled by any other type. This position is not unfair to the hydraulic elevator, as you, Mr. President, have pointed out that each of the various devices may occupy its own field.

There is, within my personal knowledge, no motor-driven hydraulic elevator equipment in constant daily service in Manhattan. There are several such sets operating as auxiliaries for night and Sunday service to systems normally supplied by steam-driven pumps, and a number of them in residences and in other small installations, but neither class is to be considered in this connection.

Within the past few weeks the owners of a Broadway building, eight stories in height, installed a 50-horse-power motor-driven set, replacing steam pumps for the operation of three hydraulic elevators, but it did not pass the acceptance test and is now being removed.

One of the important buildings mentioned in Mr. Sever's paper, was originally arranged for several hydraulic elevators, to be driven in the usual manner by steam pumps, supplied from high-pressure water-tube boilers, which were also to furnish steam for the dynamos for lighting. This plan was changed, electric elevators were installed and are operated with the lighting from the Edison mains and are likely to remain in successful, continuous operation.

There are about ninety cases in this city in which steam and hydraulic elevators have been changed to direct-electric, and the case of a single building is pending in which a number of elevators will be changed in that manner.

The only instance referred to by Mr. Sever, in which the elevators are supplied from a private plant, is the one of which the results of the elevator tests are shown in Fig.4. In that case it would be interesting to show the same kind of curves with the elevator supplied from the direct and constant potential furnished from the Edison mains.

MR. F. H. TAYLOR:—Mr. Sever has admitted in the first part of his paper that the measurements upon which his table was based were more or less inaccurate, owing to the character of the instruments which were available. These measurements are important, and if corrected will change his table entirely. I therefore suggest that his paper be revised for final publication after he has procured from the manufacturers full data respecting the motors in question. I am sure that exact figures are available to him at any time. As an example of what I mean, it would change his table if he found that under no circumstances could the power factors of certain motors exceed 87 per cent., especially if even this figure was too high for the motors under their normal starting conditions.

MR. SEVER:—Mr. President, answering Mr. Taylor's invitation to use more accurate instruments and also to ask for information from manufacturers,I did not mean to imply that our instruments were inaccurate, but that with alternating current instruments, such as we employed and which we knew were correct, it is somewhat difficult to get definite readings when the current is varying so widely and rapidly.

The same elevator was tested numerous times under similar conditions in order to get an average reading on the instrument for different positions of the elevator. The swing of the needle in an alternating current instrument, as we all know, is considerable. That is, it is not dead-beat, so that the particular reading noted in the test is the average of many and as nearly accurate as it was possible to obtain it.

I thank Mr. Taylor for his invitation to get this information regarding the power factor and I will be very glad to accept it. We have called upon many manufacturers for information, and we appreciate that which has been given us. But there is one point about which we have not been able to get sufficient data, and it answers one of Mr. Mershon's questions; that is, regarding the weights involved. Many do not seem to know how many pounds of metal there are in the moving parts of the elevator system. For instance, the overweight noted in one of the columns has been a very difficult quantity to ascertain. Some of the various manufacturers in answering our inquiries have said they did not know. The way in which they determined the overweight was to put certain weights on the balance and when the current going up was equal to the current going down with a certain number of passengers, I think two, that was the overweight. How much it was they did not know. They simply put on weights until that condition was established. An attempt was made to determine the overweight from electrical readings and some of the results which are given here have been determined in that way. The total weight of the system is therefore not easily obtainable. The power factor may be more easily ascertained. The acceleration is about the same with an alternating motor going up and going down. The tests on that motor were made with a stop-watch, and it is reported that the results were approximately the same. The reason for the smaller difference with the motors coming down is that the direct current motor has to lift the overweight more rapidly, the acceleration being a little greater, and, therefore, takes more power, and the difference between the alternating and the direct in that case is less than in the case of the rising. Of these elevators, 3,300 are operated from central station mains, if I remember correctly. There are one or two in the tests reported, operated from local plants and the elevator in the Horace Mann School is one of these. The kilowatt hours per car-mile have not been ascertained, at least are not given here, but they are available, or they may be calculated from the curve sheet.

Mr. Wellman:—Since so much stress has been laid upon the starting current required, I think it may be of interest to call attention to one system of operating electric elevators that has been exploited to such an extent that it has been given a sub-class in the Patent Office—the running rope system. This is based on the old principle of the Chinese windlass; an endless rope, forming essentially three loops, one of which passes over an idle pulley by which the car is raised or lowered, and two other loops embrace driving pulleys of two motors. When these are operated in different directions at uniform speed, or rather the same peripheral speed, the car remains stationary. Then by varying the peripheral speed at either of the motors the car is caused to ascend or descend. By this means I understand that the starting current is kept down to the extent that the inertia of the motor armatures does not have to be overcome in starting the car.

MR. IHLDER:—I believe that the running rope elevator will be found to take about the same starting current as a standard elevator. Though the armatures of the first type are in motion, they still have to start and accelerate the load, and this is done by shunt motors, while the standard elevator motors use heavy compound winding and thus gain sufficient to balance the armature momentum.

MR. SEVER:—I want to correct one impression regarding curve sheet No. 4. The voltage noted there is that across the brushes of the motor and increases as the resistance is cut out, finally reaching the line voltage of 110. It simply shows a rising voltage with the cutting out of resistance.

PRESIDENT STEINMETZ:—Gentlemen, before calling for the motion to adjourn, I believe that, considering the interesting paper and valuable information afforded by Mr. Sever, a vote of thanks would be very proper, extending the gratitude of the INSTITUTE to Mr. Sever and his assistants in his investigations, Messrs. Rosenblatt, Daniels and Haviland.

The motion was made, seconded and carried.

MR. SEVER:—I want to thank you very much, Mr. Steinmetz, for the vote of thanks that has come through you to Messrs. Rosenblatt, Haviland and Daniels, who are here to-night and who have done such good work in obtaining these results. They have certainly gone through a strenuous experience to get them. I thank you very much.

On motion the meeting then adjourned.

DISCUSSION AT CHICAGO, APRIL 25, 1902.

The paper on " Power Consumption of Elevators Operated by Alternating and Direct Current Motors," by Mr. Sever, was read by Mr. Lyman.

Chairman Pierce read written discussions which had been received from Mr. H. H. Humphrey of St. Louis and Mr. S. G. Neiler of Chicago.

MR. HENRY H. HUMPHREY [*Communicated*]:—This paper by Mr. Sever is one of particular interest to me at this time, as I have just been called upon to decide between the use of alternating current and direct current for a factory power plant, consisting of two 75 k.w. units, about 150 rated h.p. of electric motors and about 30 k.w. of incandescent lighting. There are seven elevators in the plant, two of which are at present supplied by direct current from a central station; three are direct-connected steam elevators, which it is desired to replace with electric elevators; and two are at present belt-driven freight machines. In this particular plant there are good reasons for the use of alternating current motors, but the elevator problem is really the deciding one in favor of the use of direct current.

I have had considerable experience with direct current elevators, but my experience with the alternating current, direct-connected electric elevator has been limited to one machine, and that did not prove satisfactory. I am disappointed that the author of this paper does not discuss the results of his tests more fully, as I find it impossible, from the data given in Table I and the curves he has submitted, to reach any definite conclusion regarding what is the better type of elevator equipment. What I have to say, therefore, is rather in the way of asking for information than adding to the paper.

In the first place, I notice that the direct current machines tested are all of the latest magnet-control type and represent the development of half-a-dozen years in the improvement of starting and controlling apparatus for direct current, direct-connected elevator motors. On the other hand, four of the six alternating current elevators have no control whatever and the comparisons shown in Curves No. 1 and No. 2 are made with all six elevators, which include the four without any automatic control. This is evidently unfair to the alternating current elevator machines.

The next point that occurs to me, is that all the tests are made at comparatively light loads. Only one test on one machine is made at anywhere near full rated load of the elevator, and in that case the current returned to the line on the down trip is not given. It will be admitted, I think, that elevator tests should take into consideration the consumption of power during the entire round trip, and that the full rated load for which the elevator is designed is the only proper loading for testing. When the balanced load is taken during test, the measurements show nothing except the friction of the machinery, the power required for the acceleration and the motor losses. Tests taken with but one or two passengers on a machine, it seems to me, are subject to criticism, as they show little more than in the case when the load is balanced. What is desired is to know what the elevator will do when operating under normal full-rated load conditions.

The high power factor at starting given in the table is surprising, and is a strong point in favor of the alternating current elevator motor. If the power factor is as high as given, why do alternating current elevator motors have such a bad effect in the fluctuation of voltage on the line? It has been found perfectly practicable to operate direct current passenger elevators and high economy incandescent lamps from the same bus-bars in isolated plants where the lighting units are not smaller than 60 k.w., and the passenger elevator machines do not exceed 2,500 pounds capacity at 250 feet per minute. I do not know of any case, however, where alternating current, direct-connected elevator machines of similar capacity have been operated on lighting circuits from generators of similar sizes in isolated plants. In the case referred to above, a 20 h.p. two-phase motor, direct-connected to an elevator, produced a variation in voltage on a 100 k.w. direct-connected alternator of 6 to 7 per cent., even when the starting current per phase was cut down to 50 amperes at 200 volts. I would like to know why the regulation is affected so seriously if the power factor is as high as given.

The power factor when running is also surprisingly low. The author suggests that this is due to the size of meter used, but as the table does not give the horse power of the alternating current motors, no conclusion can be drawn on this point. Curves 1 and 2 also show that the k.w. when running, by which I mean the k.w. at the middle of the travel between top and bottom of hatchway, is much higher with the alternating current than with the direct current motor. This indicates that the efficiency of the alternating current motor is much lower than that of the direct current machine. This is contrary to my expectations, and may also be influenced by the size.

It is to be noted, however, that if we take the column in Table I, showing the " power in k.w. for running " and confine our reading to those where the load is two persons and three persons, both up and down, the average of the direct current tests is 4.39 k.w., while the average of the alternating current tests is but 2.31 k.w. This indicates that the alternating current machines are more efficient than the direct current machines, and is not consistent with the data given in the curves. It may be, however, that the " power in k.w. running " gives the average k.w. after the first 2½ or 3 seconds allowed for starting was taken off. It would be interesting to know how the " powers in k.w. for running " given in the table are obtained.

It would be desirable to have a careful comparison made between these two types of elevators of equal rated capacity as to loads and speeds, having the same amount of counterweights,and equipped with the latest type of starting apparatus for each type, giving acceleration to the loads in the same period of time for each, and then to have records made under full-load conditions with account taken of the amount of current fed back to the line on the down trips. It is to be hoped that the discussion of this paper will bring forth the results of some such tests.

PROF. P. B. WOODWORTH:—I have had absolutely no experience with the alternating current motor in elevator service, and know nothing about it, but Mr. Sever's paper is quite a surprise to me for a number of reasons; first, because of what I would call poor operation of the direct current motors, as they do not come up to what I expected of them. I have made some tests of the alternating current motor with seemingly very much better results.

In the second place, the alternating current motor, or the induction motor, is the motor that is to take the place of the shunt motor, and, as we all know, the shunt motor is not designed to run an elevator and cannot do so. It is not the proper machine. As I said before, I am surprised to find that the alternating current motor made anywhere near as good showing as this paper indicates. Any type of apparatus where we must have manual control, or where accumulative or compound winding or anything of that kind are necessary—the plain induction motor as we know it at the present time—is not suitable for the work, but it seems to be very much better suited for the work than I had thought.

MR. PIERCE:—In regard to the question of the control of the alternating current motor, as referred to by Prof. Woodworth, it seems that some of the motors used in these tests were plain induction motors, but the other motor, to which he called particular attention, was of a type having resistance in the armature, and this type, as I understand it, would be controllable. In fact I had supposed that there would be even better control than is shown by this paper. I think that Mr. Lyman knows a good deal about this particular kind of control, and I will ask him if he cannot tell us something about it.

MR. JAMES LYMAN:—I would like, Mr. Chairman, to call upon Mr. Lofts, engineer for Swift & Co., who has been investigating this question.

MR. DAVID LOFTS:—We are interested in freight elevator service more than anything else. Our present type is the friction elevator, run by an induction motor, and the question came up as to whether it was desirable to continue to operate this kind of an elevator or adopt a type in which the motor was stopped and started each time that the elevator was used. I did not come prepared with any figures. Tests were made on a passenger elevator, where the lift was 31 feet, the speed per minute 125 feet, and the capacity 3,000 pounds; lever control three-phase induction motor, with external resistance in series with armature. The k.w. hours per thousand pounds per car mile were 15.37. At the works of Swift & Co. a squirrel cage induction motor, running continuously, is used on the friction elevator. With a 64 ft. lift, speed per minute 140 feet, capacity 3,000 pounds, the k.w. hours per thousand pounds per car mile were 16.5. The friction elevator dropped the load and did not consume any current going down.

MR. PIERCE:—Were these figures of the power per car mile based on the round trip in each case?

MR. LOFTS:—Yes.

MR. LYMAN:—I would like to add a word or two to what has been said. The readings that were made on these tests were only brought to my attention this evening, so that I have not made a careful study of them, but the results given in the paper, as has been said before, do not appear to give proper credit either to the direct current or alternating current motor as adapted to the best elevator service.

Prof. Woodworth remarked that the induction motor was similar in its characteristics to the shunt-wound, direct current motor, and he is exactly right, and for that reason the induction motor is not a well-designed motor for elevators. It is capable however, of giving very good results, and the motor on which Mr. Lofts made some tests at Carroll Bros.'s, referred to by him a few moments ago, shows what can be done in elevator practice, taking alternating current from a commercial lighting circuit. In this case there is a 20 h.p. induction motor with resistance in series with the armature and the resistance may be varied by a controller similar to the resistance in a shunt-wound, direct current motor. Readings were taken every 15 seconds for over three hours. During that time, 171 readings showed elevator running, representing about 23 per cent, of the total time during which the tests were made, and during the time of these 171 readings there were only six readings that showed more than about 30 per cent. above full load current of the motor, and those were at the time of starting. The full load current of the motor was 60 amperes. The highest current reading at any one time was 88 amperes. There were only six readings of the 171 readings that were over 80 amperes, and only 30 per cent. of the readings approached full load, although the service of the motor compared favorably with the service of the motor given in Mr. Sever's paper. This motor had a very good controller.

There are three possible ways of running an elevator with an induction motor:

First, it may be connected in the same way as the one referred to at Carroll Bros.'s with an external resistance in series with the armature and a controller, where a most perfect control of speed is obtained, the motor being reversed by the controller.

The second is the method used in most of the tests shown in the paper this evening, where a squirrel cage armature is used. If we examine the tests we will note that the current at starting is from four to five times the full load running current of the motor, and of course this would be disastrous if the motor was connected to any lighting circuit, as it is ten or fifteen times the average running current.

The third method is that used in some of the large manufacturing establishments, like Swift & Co.'s. Here the motor is of the squirrel cage type, but is brought up to speed before the elevator is started, and then the elevator is operated with a friction wheel on a line shaft.

Mr. Lofts:—The current runs about 30 to 35 h.p. maximum?

Mr. Lyman:—The maximum power developed by the 20 h.p. motors running these freight elevators is 35 h.p.

Mr. J. W. Mabbs:—How is the friction clutch thrown in and out?

Mr. Lofts:—There is a friction wheel, and the winding drum is thrown up against the friction wheel.

Mr. Mabbs:—What holds the car when a stop is made?

Mr. Lofts:—The weight of the car draws the drum back against a brake shoe. In addition to the motor we have a fly-wheel on the friction shaft

Mr. Pierce:—I would like to ask Mr. Lyman if, in taking those seventeen readings where the current in no case exceeded the full load current, he thinks any of those readings included the current that was obtained on starting or immediately before starting—that is, the maximum.

Mr. Lyman:—Yes. I think the highest readings included the maximum current taken by the motor during acceleration. It would be difficult to take readings for three hours every fifteen seconds and not strike the maximum. Two indicating wattmeters were used in the test and the ratio of their readings showed reasonably high power factor. In eleven readings, covering a round trip of the elevator, the power factor averaged 88 per cent. There were several other groups of readings where the average power factor ran down as low as 81 per cent.

Mr. Pierce:—I would like to ask Mr. Lyman if he understands how it is that the author of this paper got .79 to .97 power factor in starting, and .14 to .68 with an average of .36 when running. Could any such result as that be obtained where an induction motor with resistance in the armature was used? The power factor would vary in the opposite way, would it not?

Mr. Lyman:—In the reading for the last motor test given in Mr. Sever's paper, the motor was arranged with the resistance in connection with the armature, but I could not see why the power factor should be high at starting. With such an immense current it seemed as if something must be wrong.

I wondered about another thing in looking over this paper. These motors are all two-phase motors, and the current apparently is the current in one phase, while it is compared with the current in the direct current motor. Of course one-half the energy is transmitted to the motor from one phase, so that the current for the two-phase motor should probably be double what it is indicated to be, and it is probably a great deal worse than it looks, as far as the starting current is concerned. It does not seem wise to me to use a squirrel-cage armature induction motor there, when the motor is to be started and stopped while the elevator is running; but it may be used to advantage in ordinary shop practice such as at Swift & Co.'s, where it is very successful, and in riding in these elevators one would scarcely realize what an apparently crude arrangement of regulation they have. The elevators move very smoothly and the motors stand an excessive load.

Mr. A. D. Ayres:—It seems to me that the author is comparing the best form of direct current with the very worst form of alternating current; not only that, but wrong sizes. This is very evident, because if we take an induction motor running at anywhere near full load, we get .85 to .95 power factor. I think the author either read his instrument backward or his connections were wrong.

Then, in regard to using a squirrel-cage armature motor; a squirrel-cage armature motor is all right in certain cases, if properly selected for the work, and properly installed. There are two types of variable speed motors—one having a short-circuiting ring where the control is obtained by taking out taps; the other and best way is by inserting resistance in the revolving coils. In that way the starting current will be very small compared with the running current. We have about half-a-dozen of these running now in Chicago, and quite a number are being installed. I think that this whole idea of comparison is wrong, because the comparisons have not been made properly, and it seems to me that the man who made up this report was in error.

MR. PIERCE:—In looking over these tests it seems to me that all these loads were too light to form any basis of judgment. Nearly all the loads were such as would not give a fair comparison.

MR. MABBS:—My experience has been confined to direct current electric elevators, but, judging from this paper, the comparison seems to be very unfair to the alternating current motor. It seems to me like attempting to compare a lumber wagon with the most modern type of automobile. In this case a very crude alternating current machine is compared with the very latest and most up-to-date direct current machine. At the same time it is quite a question whether the alternating current machine is really adapted for the purpose. From this paper it would seem that it is not, and some very important data have been left out—that is, the speed of the car when taking into consideration the starting current. Every one knows that the starting current depends upon the speed at which the elevator is running and the period of acceleration. One may start an elevator very slowly and the amount of current consumed will be very little above the running current. At the same time if that same elevator is started in a very short space of time, the starting current will be very high, and on that account the figures given here ought to give the speed and the period of acceleration.

The author makes comparisons between two different machines I should judge one of them was running at a speed of 160 feet a minute, and, if I am not mistaken, the other was running at a rate something like 500 feet per minute, and he compares the starting current of one with the other. It makes a great difference whether that car is started up in five, six or ten seconds, or whether it is started in from one to three seconds.

The most important essentials for electric elevators at the present time are high speed and quick acceleration, and the desire is to get these two features and get them with as small a current consumption as possible. That is the problem that is before electrical engineers in the elevator line to-day, and at the present time it has not been very well solved. The direct current machines with which I have had experience take a period of acceleration of about five seconds, and they make a speed of 400 feet per minute. They take at least twice as much starting current as running current; in fact, sometimes more. I think it is an impossibility to start a car up with 20 per cent. rise of current and fulfil the conditions under which an electric passenger elevator is expected to run to-day. These conditions are pretty nearly the conditions of an old hydraulic elevator. People want it to run 500 to 600 feet a minute and start up in two or three seconds.

The efficiency of the best electric elevator in the market to-day is about 50 per cent. Many of those referred to in this table, I should judge, have an efficiency far below that. The best types of electric elevators that I know of give an efficiency of about 50 per cent. The makers of some of them claim that they will give 60 per cent., and I know of some makers who claim that their elevators will give 75 per cent., whereas they really give but about 35 per cent. These are just plain facts in the case.

In regard to the question of power, I have kept a record of some electric elevators for a period of about five years, and have kept the car miles and the kilowatts per car mile figured up monthly, and what is claimed by the elevator trust to be the best high-speed electric elevator produced to-day takes about 5½ k.w. per car mile under actual running conditions, and the actual running conditions are from an empty car to a load of 2,500 pounds, and running at about 400 feet a minute.

Assuming that the cost per kilowatt in an ordinary plant is something like 1¼c., this would make the cost per car mile about 6.6 cents per car mile under actual running conditions, on the elevator referred to. The k.w. hours consumed were 15.37 and on a basis of 1¼c. would equal 19.21 cents per 1,000 lbs. per car mile. This does not show as good economy as direct current or hydraulic elevators. The best types of hydraulic elevators will run under 3½ c. per car mile, and the question comes down to the point where the electrical engineers must make an elevator that will compete against the best type of hydraulic elevator. If the alternating current is so far below the direct current in efficiency, as shown in this table, and the direct current is so far below what it ought to be, the chances for the alternating current are very slim.

MR. HOBART:—I thought it might be well, inasmuch as the subject of our special elevator was brought up, to say something about the points that led us to adopt that type. Most of the elevators were run by a friction scheme similar to that shown, from a main line shaft. In adopting alternating current in one of our later plants, we put in Crane type motors in some ten elevators, these, however, being only a fraction of all our power. Other conditions in our general plant led us to adopt the alternating current as the best for the whole plant. The elevators were only a fractional part of the system. We found that we had some trouble with the elevator motors—more trouble than with any other part of the plant. We had lights throughout the plant on the same circuit as the motors, and we began to have considerable trouble with the fluctuation of the lights every time we started an elevator. However, our troubles were lessened considerably when we "slowed down" our elevators from about 200 feet to something like 125 to 140 feet. This led us to look into a system where we could keep the current fluctuation down, and we devised a scheme where we had a large flywheel which took up the fluctuation current. This led us back to our original type of elevator mechanism, and the effect that we wanted to get was even current distribution throughout the plant. The question was an important one, and led us to put in this type rather than the previous type of elevator, controlled by external resistance, starting and stopping the squirrel-cage motor.

Our repairs on the previous type of elevators were at first quite expensive, owing to burn-outs of the squirrel-cage motor. Although we are still running eight or ten motors with the cage and at slow speed, they do not give us a great amount of trouble.

Mr. Mabbs:—The great fluctuation of load due to starting a high-speed elevator, as has been stated here, has a very bad effect on lighting circuits. In the case of an elevator that takes all the way from 400 to 600 amperes to start, you can imagine that the effect on the lighting system is anything but beneficial. The only way in which we overcome this trouble is by connecting up a storage battery in multiple with the generator which is running the elevator. In that way we can run the elevators with a very much smaller unit and at the same time take the enormous fluctuation off the line. The storage battery responds almost instantly; in fact more quickly than a shunt generator, and supplies the great demand for the first rush of current, whereas an ordinary engine and generator would drop perhaps ten or fifteen volts. Where a generator is run in multiple with the storage battery, the drop will be only about five volts or less.

The most efficient elevators on the market at present are those of the drum type. They start slowly and run slowly. They give the highest efficiency of anything in the electrical line today, and the repairs are comparatively small. But the repairs on some of the high-speed electric elevators are very high. This is another question that will have to be solved, that is, a machine that will run at a high speed with comparatively small cost for repairs.

There is still another question, and that is care and attention. The expense in this respect for the hydraulic elevator is exceedingly small in comparison with the present electric elevator. The electric elevator of the future will have to compete favorably with the hydraulic. It will also have to take much less starting current than the so-called high-speed electric elevators of to-day, give a much better efficiency at higher speed, and accelerate much more quickly.

Mr. Pierce:—One point which Mr. Mabbs brought out was the importance of getting a certain speed and acceleration on electric elevators. He refers to Mr. Neiler's remark where he specifies that the elevator should have a running current not to exceed the starting by 20 per cent. This I believe we have been able to obtain on elevators which will accelerate in three seconds and will run up to 250 feet a minute. We have been able to get it on the same type of elevator for the same service that other elevators will give with such starting currents as are shown in these tables, the difference being in the style of motor used. The motors which are necessary to use to give these results cost more than the motors which give this excessive starting current.

I will say in Mr. Neiler's defence that he has never attempted to use an electric elevator for the kind of service which Mr. Mabbs describes, and I presume that he would agree with Mr. Mabbs as to the advantages of the hydraulic elevator.

The style of motor to which he referred was a cumulative-wound motor, in which the winding of the series field was such that owing to the resistance of this winding and the increased magnetic induction in the motor, the starting rush was held down to about 20 per cent. in excess of full load running current, it being necessary to have the motor specially designed and to have the magnetic circuit such that it could run without sparking. It works on the series field at starting, and in order to work with the full field variation which it has from starting to running, it is necessary to have a machine with a liberal amount of iron, and the machines referred to were designed with this in view, so that they would not spark on varying loads. A machine can be obtained which will operate all right and which will not spark badly by paying an additional price, and that price is justified by taking the load off the system and by the increased economy of running.

Mr. H. H. Cutler:—I have been very much interested in the subject of electric elevators. I have looked into the alternating current motor only sufficiently, however, to form the opinion that it is never used for elevator work except when absolutely necessary, that is, when direct current cannot be obtained, and I have not heard anything said at this meeting that has led me to believe that I was mistaken in that opinion.

Looking at electric elevators from the viewpoint of efficiency, the amount of current consumed is not of very great relative importance. As Mr. Mabbs has said, the demand to-day is for an elevator that will get under way in the quickest time and not only do that, but stop quickly and smoothly. In fact, in this matter of stopping, the direct current motor is far ahead of the alternating current motor. It can not only start more quickly, but can stop more quickly.

We have had a plant in operation nearly two years operated by 40 h.p. motors at a car speed of 300 feet per minute which attain full speed in 3½ seconds. These motors are running on the lighting circuit of a large department store, and we all know that department store service is extremely severe. We never could have obtained this rapid acceleration unless we had an accumulative-wound motor having about 85 per cent. of series field winding. The elevator specifications for the new Marshall-Field building as originally drawn required bringing the car to full speed in 3 seconds, and difficulty is now experienced in obtaining full speed in that time with that installation. I think that the chief reason for this is that the firm is not using a purely accumulative wound motor, but is using some external resistance which never ought to be employed when a very quick start is desired. We have a great many plants in operation using plain shunt-wound direct current motors. Unfortunately, we have to furnish controllers for everybody's motors, some good and some poor. We do not have much trouble with plain shunt-wound motors, and such motors are used quite extensively by elevator builders. We build quite a number of controllers for plain shunt-wound motors, but they are so arranged that they cannot cut out resistance until the shunt field is fully energized. We have to make our controllers so that they will take care of this. The speed of the motor must be kept constant all the time, and stopped automatically as well as started automatically. I think that we will all agree that this paper must have been written by some one who has not had practical experience with elevators, but who devoted most of his time to measuring the current consumed in the various installations.

MR. E. B. CLARK:—There is still a very large field which I have not heard touched upon to-night, for which an alternating current motor may be adapted—that is, hoists of large capacity for use in connection with blast furnaces and such places. The most important thing about such a hoist is the stopping. There is lots of room to stop, but there is trouble if the stop is not made at the right place, and I would like to ask someone who has had more experience with the alternating current motor than I have had, what possibilities exist with respect to controlling the speed of the alternating current motor for bringing it to a standstill, or for bringing it to a slow speed before setting the brakes for the final stop. That is a very essential point in all automatically controlled hoists with which I have had experience. Mr. Ayres, who spoke in favor of the use of an alternating current motor with the resistance in the rotating part of the machine, will probably be able to answer this question.

MR. AYRES:—It depends entirely on local conditions. If the motor is properly designed, it may be arranged so that it will stop with the controller. In elevators, we do not pretend to stop electrically at all. The trouble that has been experienced before is on account of the fact that too high speed is used. About 6-poles instead of 8-poles are used and consequently a brake will not stop the elevator. The great trouble is that people buy elevators without giving enough information as to where they are to be used, and other conditions.

Mr. Clark:—If I am not mistaken, the introduction of resistance in the secondary is comparable to rheostat control. That is one thing that must be avoided in automatic control.

Mr. L. A. Nichols:—Elevators are usually contracted for by elevator companies. These companies furnish the motor, and very often they do not go beyond that point. Another fact that comes to me is that the manufacture of the alternating current motor is controlled by one or two firms—virtually one concern; that is, the combination of the Westinghouse and General Electric companies, and the price of the alternating current motor is some two or three times greater than that of the direct current motor. Taking into consideration these facts, the elevator contractor naturally will always put in as cheap a motor as he can get, and very often he installs one that is too cheap, even with direct current.

For such reasons as these, the alternating current motor is kept out of the elevator business almost entirely. I think that there is a prospect for the alternating current motor. After a while other makers will enter into competition. There is no reason that I am aware of, why alternating motors should cost more than direct current motors. I do not see why one cannot be made as cheaply as the other.

Someone made the remark here to-night that it would be a long time before electric power would be as efficient as hydraulic power, but it must be taken into consideration that hydraulic power for elevators will not produce lights.

Prof. Woodworth:—I should like to know something about the relative size of the motors, with regard to alternating and direct current.

Mr. Pierce:—As I remember it, that question was answered both ways.

Prof. Woodworth:—The way I took it was that the alternating current used, averaged about twice as much as the direct current. However, I may be wrong.

Mr. Pierce:—That was Mr. Lofts's statement.

Mr. Lofts:—I have had no experience with the alternating system, so I cannot answer that question. Under our conditions we had 20 h.p. load, 3,000 pounds, and nowhere near the full load was required to run the elevator.

Prof. Woodworth:—I have had no experience with alternating current in elevator work, but in regular service, such as in one case which I remember, we used a smaller size of alternating current motor than we used with direct current, and were able to switch from one to the other.

Mr. Pierce:—Would it be feasible, Mr. Ayres, so to adjust the resistance in the rotor as to hold the starting current down to the running current, with reasonable acceleration?

Mr. Ayres:—On such a motor as I refer to, it is impossible to get a very high rate of acceleration, without excessive starting current.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 20th, 1902.

The 19th Annual Meeting was held this date at 12 West 31st Street, and was called to order at 8.30 P. M. by President Charles P. Steinmetz.

PRESIDENT STEINMETZ:—Gentlemen, Members of the INSTITUTE and Guests: I herewith open the Annual Meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The main purpose of to-night's meeting is to receive the annual report of the Board of Directors and also the report of the tellers of the election. The annual report has been presented and distributed. It has been submitted to the Board of Directors at the meeting this afternoon and has been approved. As you will see from this report, the number of members has increased during this year from 1,260 to 1,550, a total gain of nearly 25 per cent., which is more than in any previous year. The total receipts and disbursements have reached the sum of something like $30,000, and although the expenditures of this year have been unusually heavy, due to the expense connected with the library, etc., there is a surplus of nearly $3,000, and if we proceed in the same direction, we will gather a surplus which in the future may be very useful when we desire to secure a permanent home. It appears from the report here that there is a surplus of about $18,000, in addition to a building fund, reserve fund and so forth, amounting to a considerable sum.

I now open the discussion of this report. If you desire to ask any further questions, the committee which has submitted the report, will give you the desired information. The report has been carefully gone over by the Board of Directors and has been approved. Discussion is open.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF THE BOARD OF DIRECTORS, FISCAL YEAR ENDING APRIL 30, 1902.

The Board of Directors presents herewith for the information of the INSTITUTE a report of its work during the past year, also of the financial standing of the organization.

Certain changes in the administration of affairs have been rendered necessary by the requirements of the Constitution as amended at the last Annual Meeting. On that occasion the announcement was made in the annual report of the Council of the presentation to the INSTITUTE by Dr. Schuyler S. Wheeler of the Latimer Clark Library, and the addition thereto of certain sets of the transactions of learned societies by Messrs. Edward Caldwell and C. O. Mailloux. The cost of the Latimer Clark Library has been duplicated through the generosity of Mr. Andrew Carnegie by the gift of an equal sum, due credit for which has been given in the financial statement. The entire amount has been invested in Government bonds, and about $1,700 has already been expended for the permanent betterment of the Library under the direction of the Library Committee. In order to avoid the sale of bonds, this expenditure was made from the current income of the INSTITUTE and will be suitably adjusted in the accounts.

The B ard at its May meeting authorized the employment of an expert accountant to thoroughly examine the books of the Secretary and the Treasurer. This has been done, and by recommendation of the Finance Committee the system of accounts was reorganized upon a double entry basis. No other change was found necessary, as the system already developed was found satisfactory by the accountant in every other particular.

By direction of the Board, the Committee on Standardization was instructed at the June meeting to revise its previous report upon standardization and bring it down to date, with such additions, modifications and amendments as in the judgment of the Committee seemed desirable and proper. This revising work of the Committee has been completed, and the report in its final form will probably be brought before the INSTITUTE at the June Convention for final consideration.

At the July meeting of the INSTITUTE the bank account of the INSTITUTE being reported at $12,762.54, it was voted that Government bonds, face value $8,000 be purchased and placed by the Secretary and Treasurer in a Safe Deposit compartment. These instructions were carried out and the bonds named as well as $7,000 in bonds previously purchased, were deposited in the vaults of the Colonial Safe Deposit Co., 220 Broadway.

The annual Convention was held in the New York State Building, on the grounds of the Pan-American Exposition. Twenty-one foreign guests were present, and the sessions of the Convention were well attended and of unusual interest. Arrangements are now being made for the next annual convention at Great Barrihgton, Mass., June 18th to 21st, and the various committees are well satisfied with the outlook. Among the general subjects to be presented and discussed are steam turbines, electric railroading and electrical engineering education. A number of papers upon miscellaneous topics will also be presented.

As the room occupied by the Library in the Havemeyer Building was leased by other tenants from May 1st, 1902, the Library Committee in conjunction with the Secretary was empowered to engage other quarters in the vicinity, as it was impossible to obtain the necessary space at 26 Cortlandt Street. Suitable accommodations were accordingly engaged at 95 Liberty Street, one block south from the quarters occupied since November, 1894, and the Library and offices were consequently moved during the first week in May, 1902.

The annual dinner of the INSTITUTE was given at the Waldorf-Astoria on January 14th, 1902, at which Signor Marconi was the guest of honor. Two hundred and eighty-seven members and guests were present.

At the February meeting of the Board, resolutions were passed recommending the adoption by Congress of a bill authorizing the introduction of the metric system by Congress with due regard to the interests of manufacturers.

On April 21st, the INSTITUTE, in conjunction with Columbia University, gave a reception to Lord and Lady Kelvin, which was participated in by the American Association for the Advancement of Science, the New York Academy of Sciences, the American Physical Society and the American Mathematical Society, at which the attendance was about 2,000.

There have been held during the year the Annual Convention at Buffalo, the Annual Business Meeting and nine monthly meetings in New York City, also four local meetings at Chicago and two at Minneapolis. Preparations are being made for local meetings next season at Cincinnati and St. Louis.

The total membership at the close of last year's report was 1,260, classified as follows:

Honorary Members	2
Members	387
Associates	871
Total	1,260
Associates elected May 1, 1901, to April 30, 1902	328
Total	1.588

Resignations have been received and accepted during the year from the following members and associates who are in good standing:

Members—Charles H. Haskins, Clark C. Haskins, Giles Taintor, F. T. J. Haynes, Leigh Carroll and R. E. Dunston.

Associates—W. C. Peckham, E. C. Sharpe, Emile Berliner, James E. Denton, W. M. Stewart and William Wallace.

There have been the following deaths during the year:

MEMBERS:

A. LANGSTAFF JOHNSTON   JOHN WARING.

ASSOCIATES:

FRED. W. WOOD, RICHARD R. BRYAN, CHARLES LEMON,
ARTHUR B. WOOD, JAMES H. LORIMER, C. WALDRON SWOOPE.

Total Deaths	8
" Resignations	14
Dropped as Delinquent	7
Elected but not yet Qualified	10
Total	39

Leaving a total membership of 1,549 on May 1st, 1902, a net gain of 239 This exceeds the net gain of the previous year by 212.

The membership is classified as follows :

Honorary Members	2
Members	405
Associates	1,142
Total	1,549

A list of associates elected during the year accompanies this report, and the names appear in the printed TRANSACTIONS.

The reports of the Secretary and Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of the receipts and disbursements during the entire year.

The financial report is in slightly different form from previous reports, having been prepared by an expert accountant, and is based on the distribution of accounts as they now appear in the ledger.

ASSETS.		LIABILITIES.	
Cash	$ 1,885 17	Library Fund	$ 7,455 84
Bonds, market value	16,285	Building Fund	1,100
Library	7,799	Reserve Fund	4,000
Transactions (volumes)	3,286	Compounded Membership Fund	3,600
Office Furniture and Fittings	212 75	Surplus	18,464 76
Badges	80 50		
Catalogue Type and Cases	191 82		
Congress Books	480 00		
Accounts Receivable	4,399 86		
" " Secretary Petty Cash	500		
	$34,620 10		$34,620 10

STATEMENT OF RECEIPTS AND DISBURSEMENTS

FOR YEAR ENDING APRIL 30, 1902.

Receipts.		*Disbursements :*	
Entrance Fees	$ 1,530	Stenography	696 65
Current Dues	13,561 82	Stationery and Printing	830 24
Past Dues	1,298 41	Postage	797 70
Advance dues	135 10	Express	231 01
Life Membership Fund	600	Conversazione	427 41
Transactions Sales	875 49	Badges	297 48
" Subscriptions	434 15	Expenses General	465 27
Binding	32	Certificates	20 75
Advertising	738 59	Office Fittings	67 82
Conversazione	280 85	Salaries	4,318
Electrotyping and Engraving	22 65	Engraving and Electrotyping	718 90
Badges	405 23	Publishing Transactions	4,135 62
Transfer Fees	266	Rent	1,459 08
Congress Books	2 10	Advertising Commissions	186 75
Building Fund	100	Binding	390 30
Interest	372 80	Meeting Expenses	1,064 91
Library Fund	7,335 62	Office Expenses	107 92
		Library "	2,242 33
		Library Fixtures	635 49
		Bonds	8 720
	$27,990 81		$27,808 63

The total receipts for 1902, exclusive of donations to the Library Fund, were $7,459.15 in excess of 1901.

The total disbursements for 1902, exclusive of Bonds purchased, were $7,369.02 in excess of 1901. Of this amount, $2,877.82 is directly chargeable to the Library, making the total of disbursements for 1902 over 1901 $4,491.20.

Due from Member's account of Entrance Fees and Dues	3,869 20	
Unpaid Bills, none		
Total Cash Receipts	27,990 81	
Less Contribution to Library	7,335 62	20,655 19
Total Cash Disbursements	27,808 63	
Less Bonds Purchased	8,720	19,088 63
Gain during year		1,566 56

Property on hand according to inventory May 1, 1902.

Office Furniture and Fittings	212 75
Badges	80 50
Transactions	3,286
Congress Books	480
Printing Material	191 82
Library	7,799
	12,050 07

TOTAL NET ASSETS.

Cash	1,385 17	
" Secretary Petty Cash	500	
Bonds, Market value	16,285 00	
Inventory (as above)	12,050 07	
	$30,220 24	
Total Assets last year	15,375 76	
Increase		$14,844 48

This increase is accounted for as follows:

Contributions to Library (Cash)	7,335 62
Increased value of Library	6,184
Surplus from years' business	1,324 86
	$14,844 48

Respectfully submitted,

RALPH W. POPE,

Secretary.

TREASURER'S REPORT.

From April 30, 1901, to May 1, 1902.

George A. Hamilton, Treasurer, in Account with American Institute of Electrical Engineers.

Dr.

Balance from April 30, 1901	$ 1,451 48
Received from Secretary, April 30, 1901, to May 1, 1902	27,742 32
	$29,193 80

Cr.

Disbursements from May 1, 1901, to April 30, 1902, on warrants from Secretary, as approved by Committee on Finance and Board of Directors, Nos. 1358 to 1555 inclusive	$27,808 63
Balance to New Account	1,385 17
	$29,193 80

By instructions of the Board of Directors, Government Bonds have been purchased during the year at a face value of $8,000, upon which a premium of $720 was paid. This amount is included in the above disbursements.

Resepctfully submitted,

GEO. A. HAMILTON,

Treasurer.

PRESIDENT STEINMETZ:—If there is no discussion, we will proceed to the next business of the meeting, which is to hear the report of the tellers regarding the election of officers. I call upon the Chairman to give us the report.

The Committee of Tellers, W. J. Hammer, Chairman, F. C. Bates, J. J. Bellman, S. D. Collett and F. E. Kinsman, reported the results of balloting as follows:

FOR PRESIDENT.

Charles F. Scott	501	C. T. Hutchinson	3
C. O. Mailloux	7	F. A. C. Perrine	3
M. I. Pupin	4	L. B. Stillwell	1
W. L. R. Emmet	3		

FOR VICE-PRESIDENTS.

Bion J. Arnold	486	Calvin W. Rice	6
C. O. Mailloux	484	J. W. Lieb, Jr.	5
Schuyler S. Wheeler	467	A. E. Kennelly	4
W. D. Weaver	33	H. J. Ryan	3
C. S. Bradley	16	Townsend Wolcott	2
Wm. Stanley	11	J. J. Carty	1
L. B. Stillwell	11	W. L. R. Emmet	1
A. J. Wurts	10	W. E. Goldsborough	1
Louis Bell	6	C. F. Scott	1
F. A. C. Perrine	6		

FOR MANAGERS.

Townsend Wolcott	501	J. S. Peck	4
Gano S. Dunn	492	L. B. Stillwell	4
E. H. Mullin	462	H. A. Wagner	4
C. A. Terry	458	W. J. Hammer	3
R. T. E. Lozier	42	G. T. Hanchett	3
F. A. Pattison	16	J. W. Lieb, Jr.	3
C. C. Chesney	10	T. C. Martin	3
W. B. Potter	10	P. C. Hewitt	2
A. J. Wurts	7	L. B. Marks	2
H. G. Stott	6	R. N. Baylis	1
Calvert Townley	6	C. T. Child	1
Max Osterberg	5	P. G. Gossler	1
H. J. Ryan	5	Robert Lundell	1
F. V. Henshaw	4	C. O. Mailloux	1
P. M. Lincoln	4	W. L. Puffer	1
L. A. Osborne	4	Fitzhugh Townsend	1

FOR SECRETARY.		FOR TREASURER.	
Ralph W. Pope	518	George A. Hamilton	518

PRESIDENT STEINMETZ: Gentlemen, you have listened to the tellers' report on the result of our annual election. I believe I voice the sentiment of all by saying that we can congratulate ourselves on the personality of the President we have selected, whose name and general reputation offer a sufficient guarantee that the next year will be prosperous and successful.

In connection with the election, I desire once more to draw your attention to the provision of the new constitution, excluding associate members from the presidency and vice-presidency, and I desire to remind those members who are fully qualified to become full members but who have not complied with the formalities, to apply for transfer. All those who are entitled to full membership should make application.

This business being over, I call upon the Secretary to make an announcement.

SECRETARY POPE:—At the meeting of the Board of Directors this afternoon, the following associates were elected:

NAME.	ADDRESS.	ENDORSED BY
ASH, WALTER VOORHIS,	Chief Electrician, Raritan Copper Works; residence, 79 State St., Perth Amboy, N. J.	W. S. Brewster. E. G. Elliott. R. W. Pope.
BERRY, A. HALL,	Manager of Electrical Department, H. W. Johns-Manville Co., 100 William St., New York City; residence, Montclair, N. J.	Joseph Sachs. Calvin W. Rice. Geo. F. Sever.
BROWN, WALTER EVERETTE,	Central Office Assistant to Superintendent, N. Y. & N. J. Telephone Co., 81 Willoughby St.; residence, 763 Nostrand Ave., Brooklyn, N. Y.	W. J. Hammer. Alex. MacFarlane. J. C. Reilly.
BROWNE, WILLIAM HENRY,	Treasurer, General Manager and Director, Stanley Instrument Co., Great Barrington, Mass.	Wm. Stanley. C. W. Rice. F. A. C. Perrine.
CONWELL, WALTER LEWIS,	Westinghouse Electric and Mfg. Co., 120 Broadway, New York City; residence, Upper Montclair, N. J.	S. L. Nicholson. P. T. Brady. C. F. Scott.
DARBY, WALTER RAINES,	Salesman, General Electric Co., 44 Broad St.; residence, 18 Summit Ave., Westfield, N. J.	F. C. Bates. J. J. Mahony. G. F. Sever.
DAY, CHARLES,	Engineer of Works, Link-Belt Eng. Co., Nicetown; residence, Germantown, Philadelphia, Pa.	R. D. Lillibridge. Louis Bell. T. V. Bolan.
DODGE, KERN,	Electrician, Link-Belt Eng. Co., Nicetown; residence, Germantown, Philadelphia, Pa.	R. D. Lillibridge. Louis Bell. T. V. Bolan.
DOUBRAVA, HARRY WILFRED,	Engineer, Bullock Electric Mfg. Co. and Wagner Electric Mfg. Co., 220 Broadway, New York City.	R. T. E. Lozier. W. B. Spellmire. R. B. Owens.

FARMER, ELMER ELLSWORTH, Engineer of Experimental Department, Stanley Electric Mfg. Co.; residence, 105 Wendell Ave., Pittsfield, Mass.	F. A. C. Perrine. C. C. Chesney. John F. Kelly.
FROMHOLZ, ANTON JOHN, Electrician in charge, U. S. Navy Yard, residence, 1177 Greene Ave.,Brooklyn,N.Y.	Frank Martin. H. Spochrer. S. L. Nicholson.
HARISBERGER, JOHN, Assistant Superintendent, Snoqualmie Falls Power Co., Snoqualmie Falls, Washington.	Eugene Maxwell. S. Z. Mitchell. T. A. W. Shock.
HARRIS, WILLIAM AUGUSTUS, Manager and Engineer, The Suburban Tel. Co., Port of Spain, Trinidad.	Wm. Maver, Jr. Townsend Wolcott R. W. Pope.
HODGKINSON, FRANCIS, Mechanical Engineer, The Westinghouse Machine Co., 411 Colonial Building, Station D., Pittsburg, Pa.	C. F. Scott. L. A. Osborne. W. L. Robb.
HUNTINGTON, DAVID L., General Manager and Chief Engineer, The Washington Water Power Co., Box 1587 Spokane, Washington.	Calvin W. Rice. Samuel Sheldon. J. A. Lighthipe.
JONES, WALTER J., Engineer of Electric Department, Gas and Electric Co., of Bergen Co., 114 Main St., Hackensack, N. J.	W. J. Hammer. F. A. Scheffler. R. W. Pope.
KELSCH, RAYMOND STERLING, General Superintendent and Engineer, The L. R. H. & L. Co., 4093 Tupper St., Westmount; residence, Montreal, P. Q.	R. B. Owens. Samuel Insull. R. D. Mershon.
LUCAS, JAMES CLARENCE MERRYMAN, District Manager, Bullock Electric Mfg. Co., 8 South St., Baltimore, Md.	R. T. E. Lozier. W. B. Spellmire. Frederick Saxelby
LYNCH, JOHN COOPER, Traffic Engineer, New York Telephone Co., 15 Dey St.; residence, 104 W. 71st St., New York City.	J. J. Carty. B. Gheradi, Jr. I. W. Smith.
MOORE, ROBERT HAWTHONE, Assistant Electrical Engineer, La. Pur. Expo. Co., Mechanical and Electrical Bureau, World's Fair, St. Louis, Mo.	G. F. Sever. E. F. Schurig. W. F. White.
ORBELL, ROBERT HUGH, Electrical Engineer, British Westinghouse E. & M. Co., Paines Manor, Pentlow Cavendish, Suffolk, England; residence, 724 Whitney Ave., Wilkinsburg, Pa.	J. S. Peck. P. H. Thomas. C. E. Skinner.
PALMER, WILLIAM HENRY, JR., Electrical Engineer, Assistant to President, New York Transportation Co., 49th St. and 8th Ave.; residence, 154 W. 106th St., New York City.	J. J. Bellman. H. B. Coho. W. B. Spellmire.

RAYMOND, EDWARD BRACKETT,	Electrical Engineer, General Electric Co., Schenectady, N. Y.	C. P. Steinmetz. E. J. Berg. H. G. Reist.
RITCHIE, THOMAS EDWARD,	Business Manager, Royce Ltd.; residence, Didsbury, Manchester, England.	Wm. Maver, Jr. Townsend Wolcott R. W. Pope.
SCHMIDT, HENRY FREDERICK,	Student, Columbia University; residence, 351 West 14th St., New York City.	T. C. Martin. C. P. Poole. W. D. Weaver.
SEMENZA, GUIDO,	Chief Electrical Engineer, Edison Co., of Milan, 4 Via Paleocapa, Milan, Italy.	L. B. Stillwell. C. P. Steinmetz. C. L. Edgar.
SIEBERT, ALGERNON T.,	Experimentalist, Pyro Electric Co., 124 William St., Orange, N. J.	M. J. Wightman. R. W. Pope. Townsend Wolcott
SPALDING, PHILIP LEFFINGWELL,	Engineer, The Bell Telephone Co., Philadelphia, Pa.	Carl Hering. J. J. Carty. Theodore Spencer.
STEINLE, MAX TH.,	Electrical Engineer, with Charles J. Bogue; residence, 317 W. 22d St., New York City.	C. J. Bogue. E. R. Knowles. Max Osterberg.
STORKE, HENRY LAURENS,	2d Vice-President, The Empire State Telephone and Telegraph Co., 102 Genesee St., Auburn, N. Y.	C. T. Child. J. J. Carty. F. A. Pickernell.
THOMSON, GEORGE HUNTINGTON,	Chief Engineer, American Elevated R. R. Co., 25 Broad St., New York City; residence, Ossining, N. Y.	H. C. Wilson. W. J. Hammer. R. W. Pope.
WESTINGHOUSE, GEORGE,	President Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	C. O. Mailloux. Louis Duncan. Elihu Thomson.
WILDER, STUART,	In Testing Room, Stanley Electric Mfg. Co.; residence, 23 E. Housatonic St., Pittsfield, Mass.	D. B. Rushmore. C. C. Chesney. F. A. C. Perrine.
WINN, JOHN EDWARD,	Superintendent of Meter Department, The Cincinnati Gas and Electric Co., 220 W. 8th St.; residence, 1701 Race St., Cincinnati, Ohio.	George Hafer, Jr. J. H. Hallberg. R. W. Pope.

Total, 34.

PRESIDENT STEINMETZ:—Gentlemen, next on to-night's programme is the reading of two papers on topics referring to electric railroading, by Mr. de Muralt and by Mr. Danielson, both relating to European experience, results of the investigations of European engineers and work done abroad. Both refer to the use of induction motors for electric railways. I call first on Mr. de Muralt to read his paper.

[See page 499.]

PRESIDENT STEINMETZ:—We have listened to a very interesting paper by Mr. de Muralt. The next paper on the programme is by Mr. Ernst Danielson of Sweden, our member, which I shall abstract here. It also deals with the application of alternating current induction motors to electric railroading and especially discusses the problem of acceleration and retardation and of variable speed. It theoretically considers the solution of the difficulty usually encountered with induction motors, that they are suitable only to operate at one definite speed—the speed slightly below synchronism, and inefficient at any other speed. It is well known that where two equal induction motors are available, by connecting the induction motor in concatenation—" cascade " as our European friends call it—that is, in tandem connection or, in other words, by connecting the secondary circuit of the first motor to the primary circuit of the second motor, this couple of motors operates with efficiency at half speed; that is, the first motor running at half speed produces in the secondary a current of half frequency, the secondary current always being of the frequency of slip, that is, half frequency where the speed is half synchronism. This secondary current impressed upon the second motor makes it rotate at half speed also, so that by using two equal motors in parallel and in concatenation or tandem connection, we get the same effect as by the series parallel control of continuous current motor, that is half speed and full speed. Mr. Danielson's paper discusses the problem of securing more than two speeds by utilizing two motors separately and in concatenation, the motors having different numbers of poles, that is, different speeds. As an illustration, using a 4-polar motor and a 10-polar motor, connecting the 4-polar motor only, it will operate at a speed corresponding to 4 poles: that is, with a 50-cycle per second frequency at 1.500 revolutions. Using only the 10-polar motor, it will operate at a speed corresponding to 10 poles; that is, 600 revolutions. Using now these two in concatenation, we get a speed corresponding to the sum of the poles of the two motors or we get a synchronous speed corresponding to a 14-polar motor; that is, about 430 revolutions. Mr. Danielson shows that a fourth speed can be secured by such a pair of motors by connecting them differentially in concatenation, or so that one of the motors rotates against its torque. In this case, then, the resultant speed corresponds to the difference in the number of poles; in the present instance to 10–4, or 6 poles, that is, 1,000 revolutions. In this manner, by using two motors of 4 and 10 poles, we can get 1,500, 1,000, 600 and 430 revolutions, by utilizing either one motor separately or the two motors in cumulative or differential concatenations. Instead of using two motors of two different numbers of poles, the paper states as obvious that two equal motors can be used and the difference of speed secured by different gear ratio, as, for instance, 4-polar motors with gear ratios 4 and 10.

The second part of the paper considers then the inefficiency of acceleration of the induction motor, compared with that of the continuous current series motor under the different conditions of operation; by plain ordinary parallel operation of the induction motor or rheostatic control, without any concatenation, thereby using two induction motors of equal speed in concatenation, the ordinary method of getting two speeds; and furthermore by using two induction motors in the previously described manner, so as to get four speeds. You see the table on page 450. This is rather interesting. It shows when considering only acceleration, that the continuous current series motor, straight through, is superior, in the power it consumes for doing the same work, to the induction motor, to bring the car up at a given time to a given speed; when using electric braking, that is, when using concatenation, to return power to the line in the induction motor, the table shows that the continuous current motor is superior to the rheostatically controlled alternating current motor, but the concatenated control by using three or four different speeds gives an advantage in power over the ordinary series parallel control of the continuous current motor; that is, it consumes less power to bring the same car in the same time up to the same speed from rest. This refers, however, to the theoretical case of certain efficiencies assumed for the two motors, and assumes that the efficiency varies with the speed at the same rate, which is not exactly correct, because the induction motor falls off in efficiency for low speeds more than the series motor, since the loss in the iron increases with decrease of speed in the induction motor. But this aside, it considers only the power input, not the current input. In addition to those powers compared here, the paper states, as we all know, that there is a wattless component of current, a wattless power, which is not considered in comparison, which exists in the alternating but not in the continuous current motor.

This gives the general contents of Mr. Danielson's paper, which is extremely interesting, since it brings from an engineer of very high reputation, a very fair comparison. I may say that Mr. Danielson is very familiar with alternating current work and has been identified therewith for many years, and is an engineer of high reputation in the United States, where he has been a number of years, as well as in Europe. He brings what I consider a fair comparison of the two types of motors, when considering the induction motor under conditions as favorable as possible, that is, arranged so as to give full efficiency at four different speeds.

[See page 527.]

A paper presented at the Annual Meeting of the American Institute of Electrical Engineers at New York, May 20, 1902.

SOME NOTES ON EUROPEAN PRACTICE IN ELECTRIC TRACTION WITH THREE-PHASE ALTERNATING CURRENTS.

BY CARL L. DE MURALT.

There have recently been some pretty lively discussions between the advocates of continuous current and those of alternating current systems for electric traction purposes.

Now I wish to state right at the beginning that in the opinion of the author there are certain cases where continuous current is preferable and where alternating currents could not do the work as well, on the other hand there certainly are cases where alternating currents are particularly well adapted to solve the problems in question and where continuous current could not be used advantageously. Each special case should therefore be studied by itself, and the decision as to what system should be adopted ought to be dependent on all the different conditions which might apply to the particular case, viz., profile of the road, speed required, number of stops, traffic conditions, etc., etc. Probably most of us will agree for instance that, taking everything into consideration, the recent decision in the London Underground Railway case was really the best solution of this rather complicated problem.

In America continuous current practice has so far almost absolute sway, and it may therefore be interesting to learn something of what has been done in Europe, and more particularly in Switzerland, in the way of using alternating currents for traction purposes and to hear at the same time something about the practical results obtained on some alternating current roads that have been in operation several years.

Brief descriptions follow in chronological order of some of the most typical roads of this kind including as many details as possible, especially in regard to the Burgdorf-Thun Railway, probably the best example of an alternating current railway installation. The results of some tests made on this latter railway are also given with a few general conclusions as to the applicability of polyphase alternating currents for traction purposes.

First Tests by Siemens & Halske.—The first tests with alternating current traction were made by Siemens and Halske of Berlin, in 1892, in Charlottenburg on a specially constructed track of about 360 m. length with one curve of 40 m. radius. There were two overhead trolleys, the rails forming the third conductor. The voltage was between 500 and 600, the periodicity 50 cycles per second. An open car was used on an ordinary street railway truck, equipped with a three-phase induction motor driving one of the axles by means of a single reduction gear of 1 : 11. The speed of the motor being 1400 revolutions per minute; the maximum speed attained was about 25 km. (15 miles) an hour.

The primary winding of the motor was arranged to allow being connected in delta for starting purposes, while it was changed to star connection for full speed. The starting torque of the motor was therefore made about six times the full load running torque. The motor was also provided with slip rings on the rotor which allowed for inserting resistance into the secondary winding.

These tests showed clearly that an alternating current railway was absolutely feasible, and proved that no serious difficulties would be encountered in regard to the trolley line construction. However, the street railway problems then under consideration did not absolutely require the use of anything else but the well known continuous current system and this is probably the reason why these tests were not carried any further and put into actual practice.

The installation as just described was sent to the Chicago Exhibition in 1893, where it attracted considerable attention, but nothing has been heard of it since.

Lugano Tramways.—Brown, Boveri & Co. of Baden, Switzerland, may claim the honor of first putting alternating current into actual use for traction on a commercial scale. The tramways of Lugano, the first three-phase railway, were opened for traffic in 1895. The power station for these tramways is 12 km. outside of town, therefore transmission with 500-600 volts continuous current was impossible. Rotary converters seemed too expensive and thus it happened that all conditions were favorable for an experiment with three-phase alternating currents. The total length of the line is 4900 m. (about 3 miles) with maximum grades on long stretches of 3% and on short stretches of 6%. The transmission voltage is 5000 volts at 40 cycles. Transformers reduce this to 400 volts. Two trolley

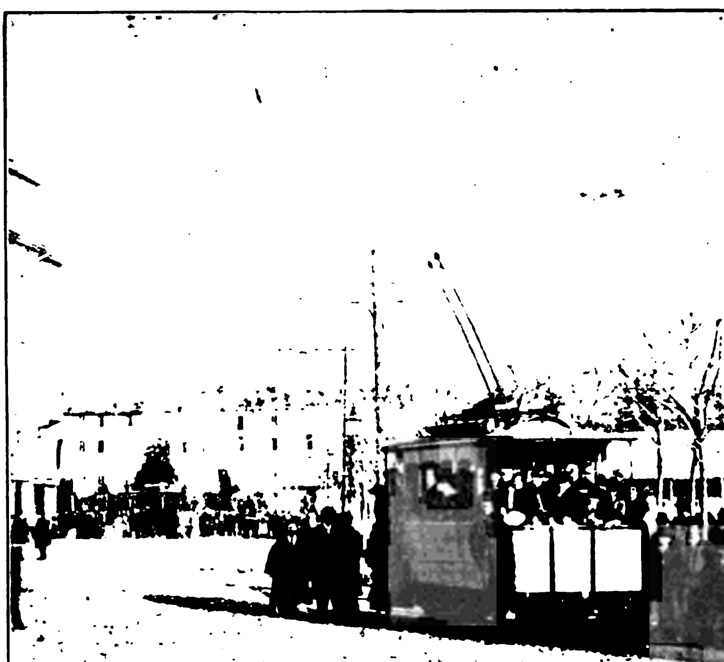


FIG. 1.

wires of 6 mm. diameter 25 cm. apart are used and the rails serve as third conductor. Cars hold 20 persons each. There is one 20 h.p. motor per car, completely enclosed, with single reduction gear 1 : 4. Speed of car 15 km. (9.3 miles) an hour. Two trolleys, one 1 yard behind the other, make contact with the two lines. Motors are started by means of a reversing switch and their speed is controlled by means of a resistance in the rotor circuit. Cars may be handled from both platforms.

Fig. 1 gives a good idea of one of these cars, and shows part of the line. Tests have demonstrated that it is possible to start with ease even on 6% grades and under more than full load.

Gornergrat Railway.—After the Lugano plant had thus proved that alternating currents could be applied to ordinary tramway purposes, the Gornergrat road was destined to show that they could also be used to advantage on a much larger scale and under the most severe conditions met on a Swiss mountain road. The total length of this line is 9 km. (5.6 miles). The difference in altitude of the two terminals is 1412 m. (4660 ft.) The maximum grade is 20%, the minimum radius in curves 80m. The gauge is 1 m. (3′ 3 3-8″) with an Abt rack between rails. The power station generates 5400 volts at 40 cycles.

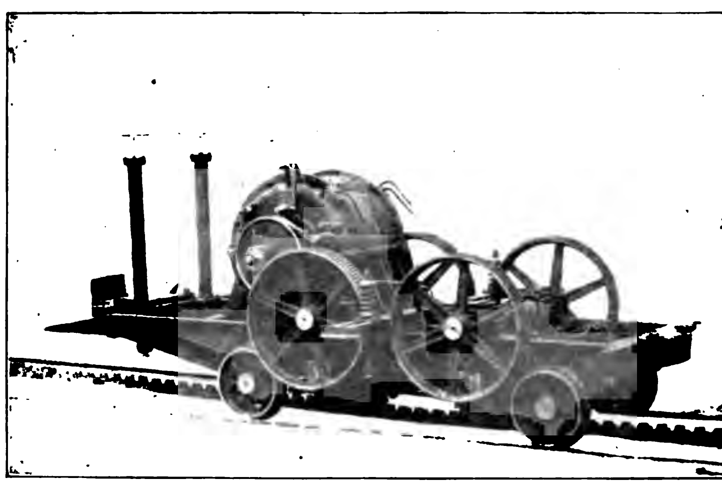


FIG. 2.

Three transformer stations of 180 k.w. each 2, 5 and 8 km. respectively from the beginning reduce from 5400 to 540 volts. The high-tension line follows a separate route. The trolley line consists of two wires of 8 mm. diameter suspended by means of cross-wires from wooden poles every 25 m. the rails forming the third conductor. The speed is 7 km. (4.35 miles) an hour. and there are 5 stations, 2.5 to 3 km. (1.5 to 1.8 miles) apart. The normal train consists of one locomotive, one main passenger car, (60 persons) and one second car (50 persons) added when needed. As a maximum there are two trains up and one down on the road at the same time. The locomotive weighs

10.5 tons, two cars 9.2 tons and 110 passengers 8.3 tons, total for one train 28 tons. The motor capacity is therefore 160 h.p. or about 180 h.p. on axles, and the locomotive is equipped with two motors of 90 h.p. each, running at 800 revolutions per minute. Each motor drives by means of a double gear one of the two cog wheels. The total reduction of gear is 1 : 12. The motors are controlled by a reversing switch through which the stator is connected to the line and by the usual starting rheostat in the rotor circuit. The rheostat is placed on the top of the motors to save space, and the switch, fuses and instruments for the same reason on the side and against the roof of the car. Two trolleys are employed on each line wire on account of the large current and in order to pass switches without making a break. The motors start on any grade under full load without using more current than when running at full speed and full load. They can start under more than full load but with proportionately more current. Fig. 2 shows the truck of the Gornergrat locomotive with one of the motors in its place. This line was completed in 1897 and opened to traffic in 1898.

Jungfrau Railway.—Before it was finished, work was already begun on a very similar line, the Jungfrau Railway. The total length of this road is 13 km. (8 miles) with a difference in altitude between the two terminals of 2100 m. (6900 ft.) The grade, almost immediately after leaving the Kleine Scheidegg station, is 10% and this is increased to 20% at about half way to the Eiger Glacier Station. From there on, the grade increases to the maximum of 25% when the line enters the tunnel. The permanent way is of metre gauge with a rack of the Strub system half way between the rails. The sharpest curve on the open section has a radius of 100 m., in the tunnel this is increased to 200 m. Water power is made use of in the valley of the White Lutschine to generate three-phase currents at 7000 volts and 38 cycles, which is transmitted by overhead wires to transformer stations along the line, where it is transformed down to 500 volts. The sub-stations are stone buildings, designed to withstand the action of the most inclement weather. They are fitted each with two 200 k.w. transformers. When the whole line is completed, transformers will be placed about every 1000 yards. There is a double trolley line as on the Gornergrat. The locomotives are very similar to those on the Gornergrat line. They weigh 13 tons complete, and contain each two 125 to 150 h.p. induction motors, driven at 760 revolutions per minute. The motor controlling devices and the contact arrangements are exactly the same as on the Gornergrat road. The cars hold 40 persons each and a normal train consists of one locomotive pushing two cars, the total weight of such a train when filled, being 28 tons as on the Gornergrat road. The speed, however, is 8 km. (5 miles) per hour.

The first section of the Jungfrau Railway to Eigergletscher was opened in September, 1898, the second to Rothstock in April, 1899, since then each year has seen further progress toward the summit, which will probably be reached in five or six years.

Stansstad-Engelberg Railway.—The next alternating current

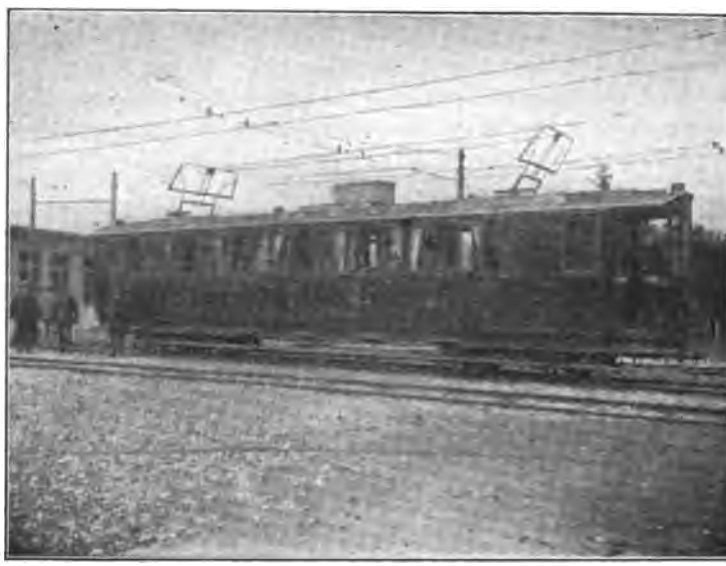


FIG. 8.

railway to be built was the one from Stansstad to Engelberg. This road, although of metre gauge only, approaches in the shape of its cars normal gauge railway conditions. The total length of the line is 22.5 km. (14 miles) The first 15 km. have small grades up to 2%, the next three km. have grades of 2.5 to 5%, then follows a section 1.5 km. long with a grade of 25% and a so-called ladder rack, finally about 3 km. more with grades of 2.5% and less. The minimum radius in curves is 50m. The power station is situated at the beginning of the rack section, about 18 km. from Stansstad, therefore it is near the point where the maximum energy is used. The voltage generated is 750 volts at 32.5 cycles, and this is fed direct into the trolley line. A 90 k.w. step-up transformer produces 5,300 volts which is transmitted to two sub-stations situated at about 3 and 7 km. respectively from Stansstad and containing each a similar transformer, reducing the voltage again to 750 volts. The trolley line construction is similar to that found on the Gornergrat and Jungfrau Railways. There are nine passenger stations on this road. Three locomotives and seven motor passenger cars are used. The cars, as shown in Fig. 3, are of the double truck type, and their total length is 14 m. Each car weighs 14 tons and

FIG. 4.

has room for 46 passengers besides being provided with a baggage compartment. The front truck carries two motors of 35 h.p. each, running at 400 revolutions per minute, with single reduction for a car speed of 20 km. (12.5 miles) per hour. The contact with the trolley line is made by means of two double contact bars attached to the roof near each end of the car. The cars may be controlled from either end-platform and the control is similar to that already described for the other roads. One automobile car is able to propel itself and to haul a trailer of about

10 tons on grades up to 2.3%. The first 15 km. section, which happens to have the heaviest traffic, is therefore worked with two cars at a speed of 20 km. per hour. The next section with heavier grades up to 5% is traversed by the motor car alone at the same speed, the motors furnishing about 80-90 h.p. for a 16-ton load on a 5% grade. At the beginning of the rack section a locomotive is added which pushes the car up the grade of 25% at a speed of 5 km. an hour. The last stretch with grades up to 2.5% is covered by the automobile alone. The locomotive not only serves for the above mentioned purpose but is destined also to haul freight trains of 20 tons total weight over the lower part of the road at a speed of about 11.5 km. an

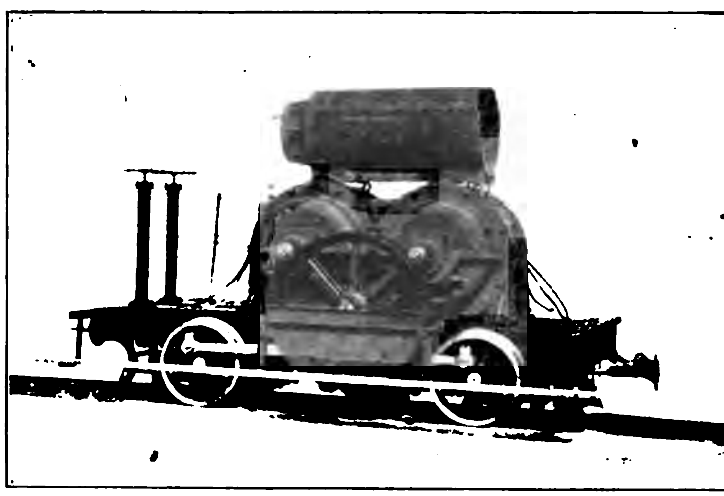


FIG. 5.

hour. Its design, therefore, varies greatly from the Gornergrat and Jungfrau locomotives. Two motors of 75 h.p. each and 650 revolutions per minute drive through a single reduction gear a counter shaft, which by means of two symmetrically placed gears drives the cog wheel placed in the center of the locomotive. This wheel is mounted on a hollow shaft fitted over the crank shaft which in its turn drives the four main carrying wheels of the locomotive On the rack section the cog wheel alone is driven. In the level country a friction coupling is set in such a manner that the two main axles are driven and the cog wheel is allowed to follow loose. The contact device is similar to the one on the passenger cars. Fig. 4 gives a good idea of this locomotive and Fig. 5 shows an interior view of its mechanical arrangement, while Fig. 6 represents a locomotive pushing one of the passenger cars up the 25% grade. The Stansstad-Engelberg Railway was opened also during 1889.

Burgdorf-Thun Railway.—The Burgdorf-Thun Railway, which was opened in 1899 and which will be described more in detail is not exactly what you would call a trunk line, yet it is of normal gauge and forms a very important link between three of the main steam lines of Switzerland. The service conditions are the same as encountered on the other Swiss railways and it uses the same size and shape of rolling stock as the main

FIG. 6.

steam roads. The total length of the line is 40.3 km. (25 miles). The main reason for adopting electric traction was that the time-table could be arranged much more conveniently than for steam traction. With steam there would have been 5 trains per day in each direction, costing per year at the least 52,000 francs for coal alone and each additional train would have cost 10,000 francs more for coal alone. Now, 50,000 francs allows with electricity as motive power the running of 10 passenger and two freight trains per day in each direction over the whole length of the line, and besides three or four trains per day from Thun to

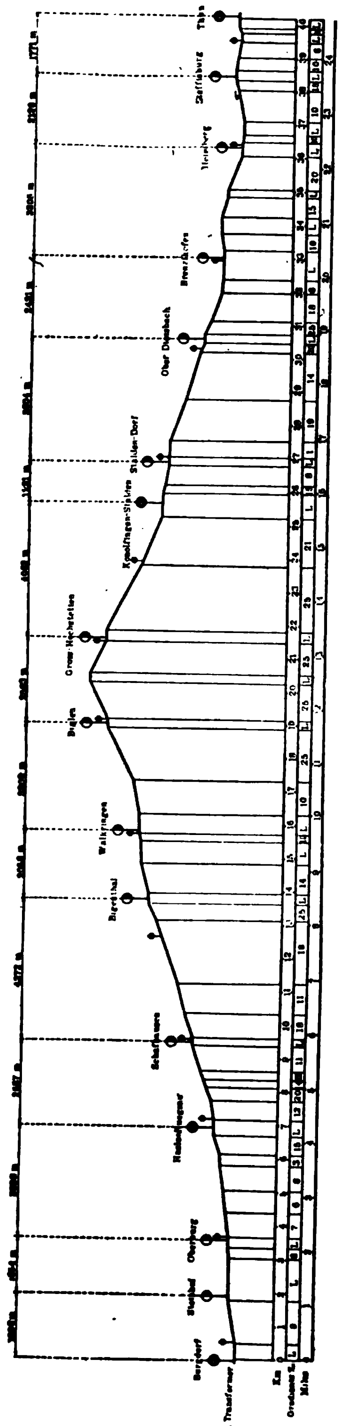

Burgdorf
Oberburg
Walkringen
Biglen
Ober Diessbach
Steffisburg
Thun
Transformer
Km
Miles

FIG. 7.

Konolfingen and back. Each train consists normally of one motor car and one or two trailers with a total seating capacity of 130-140 passengers. This means that not only is the public benefited by a better service, but the number of passengers actually carried is larger and thus increases evidently the income of the railway by a handsome percentage. Fig. 7 shows a profile of this line. There are 16 stations, four of which have connection with existing steam lines. The gauge is normal = 1.435 m., the minimum radius in curves is 250 m

The road starts at Burgdorf (536 m. above sea) and ascends with an average grade of 1.144% to the highest point almost exactly half way between Burgdorf and Thun (770 m. above sea). Then it descends with an average grade of 1.051% to Thun (561.5 m. above sea). The maximum grade in any place is 2.5%. All stations have a level stretch at least 200 m. long: 64% of the total length is straight line; 36% curves; 24% level; 23.5% on grades up to 1%; 31.5% on grades between 1 and 2% and 21% on grades between 2 and 2.5%. Rails are 12 m. long and weigh 36 kg. per metre: 45% of the track is on iron sleepers weighing 137 kg. per metre track; 55% on wooden sleepers weighing 145 kg. per metre. The normal speed was fixed at 39 km. (24.2 miles) per hour.

The energy is furnished by the power station on the Kander about 10 km. (6 miles) beyond Thun. The primary line voltage is 16,000, the number of cycles 40 per second. Fourteen transformer stations reduce this voltage to the voltage in the trolley lines which was fixed at 750 volts, this being the limit set by the federal authorities at that time. This voltage, however, seems to be increased slightly in actual practice.

The number of transformers along the line was determined by the following considerations:

The distance between two transformers along the line had to be chosen so that the drop in the line voltage did not exceed a certain predetermined value. On the other hand it was desirable to keep the number of stations within a certain limit in order to make the proportion between installed and actually working transformers as favorable as possible. It will be noticed that at any time only those transformers between which trains are actually moving are under load, while the rest are not doing any work. Finally the transformers should be placed as near the railway stations as is practicable so as to facilitate their inspection. These somewhat conflicting conditions led to the adoption of 14 transformer sub-stations with an average interval of 3 km. from one another, the maximum interval being 3.4 km., the minimum 2.4 km. The two end transformers are 500 m. from the terminals of the line.

The size of each transformer would really be dependent on the grades in its vicinity. As these grades are pretty nearly alike in this case, the capacities of the transformers worked out

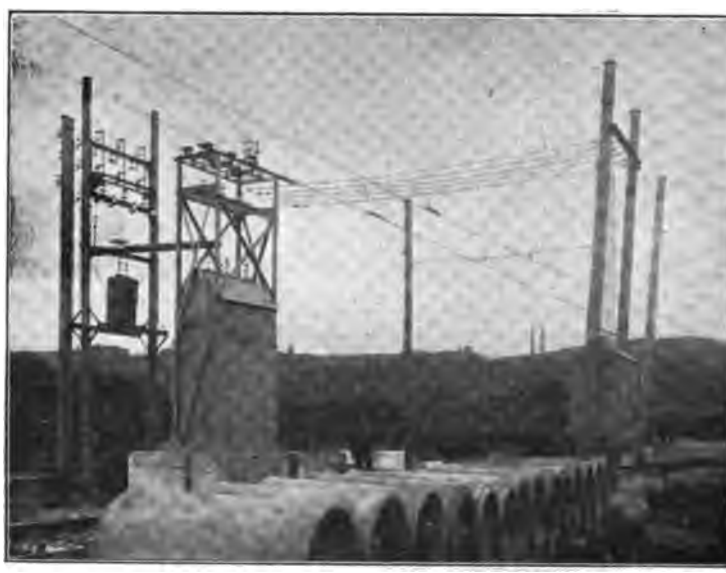


FIG. 8.

to be very much the same also, and it was therefore decided to use only one size of transformer with a maximum output of 450 k.w. This is the power required to move two complete trains. Fig. 8 shows one of the transformer sub-stations.

The high tension line first passes an emergency switch which permits cutting off the whole station. The transformer is placed in a small iron house containing in its upper part primary and secondary fuses; there is also a lightning arrester on the top of each station. The transformers are of the oil cooled type and transform from 16000 volts down to 750 volts. On the secondary side one pole is connected to earth, viz: to the rails, and the other two are carried over to the other side of the track, where they enter a special small switchboard placed in an iron box which allows cutting off the transformer from the line or else either of the two line sections meeting here from the transformer. The whole length of the line is thus effectively cut up into 15 sections. The secondary box also contains a secondary lightning arrester. Most of the sub-stations are also equipped

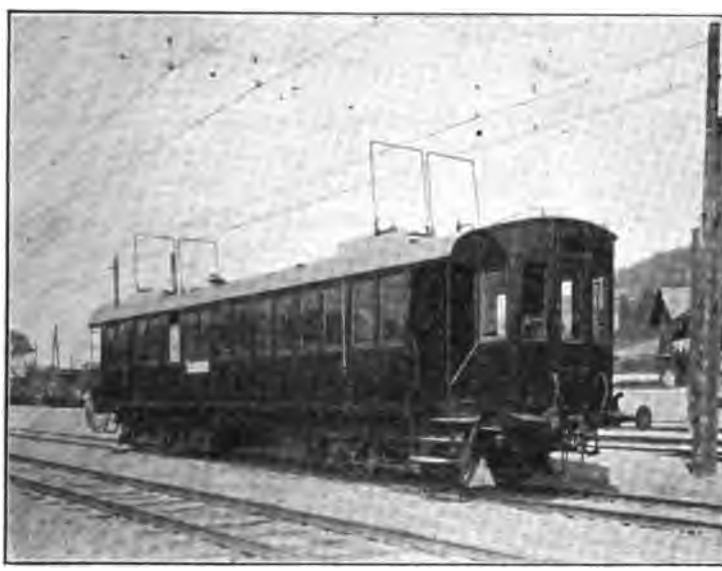


FIG. 9.

with a small 2 k.w. lighting transformer, furnishing the current for lighting the neighboring railway station.[1]

The trolley line consists of two copper wires of 8 mm. diameter suspended by means of steel cross wires from wooden poles placed on both sides of the track. These poles are normally about

35 m. apart somewhat less on curves and grade crossings. The height of the trolley wires above the rails is 5.2 m. (16 ft.) at the most, and at least 4.85 m. The rails form the third conductor and are bonded by means of a special metallic paste.

The contact devices of the cars consist of four steel frames per car as shown on Fig. 9, two on each end of the car roof at a distance of about 9.5 m. (31 ft.) from the other two, the contact bar being a brass roller of special shape. This double set was found to be necessary in order to facilitate the passing of switches without breaking the current. At the switches, the two outer trolley wires are carried right through, while the two inside ones terminate in insulated sections prolonged into a common meeting point and there anchored by insulated guy wires. The distance of 9.5 m. between the two sets of contact devices is just long enough to allow three of the four bars making contact under any condition. There is, therefore no sparking at switches, and it is possible to stop a car underneath a switch and to start it again in the same or the opposite direction.

There are two kinds of motor cars, the passenger automobile and the regular locomotive for freight trains. If this railway had been entirely independent the passenger trains would perhaps consist of one car alone. As it is, the traffic to be handled at the stations having connection with the steam roads necessitated larger carrying capacity of all the trains. The normal train composition comprises one motor car weighing 32 tons, capable of pulling a weight of about 20-24 tons in trailers on all grades and at normal speed. The motor car has seats for 66 passengers and the trailers for 60-70 more, making a total seating capacity for between 130-140 passengers.

A general view of a motor car is given on Fig. 9. It is a double bogie car with a 64 h.p. three-phase motor geared to each axle. The gear ratio is 1 : 3 and the speed of the motors 600 revolutions per minute, equivalent to a train speed of 39 km. (24.2 miles). The four motors are connected with their stators in parallel. The line current passes first through one of the two controllers, placed one on each car platform, then through automatic cut-outs to the motors. The first motion of the controller handle closes the switch shown on Fig. 10 and connects the stators to the line, at the same time cutting in four

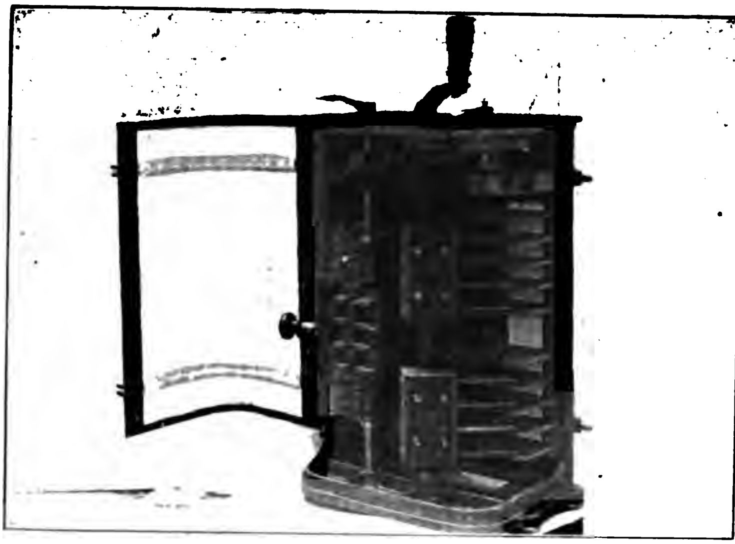


FIG 10.

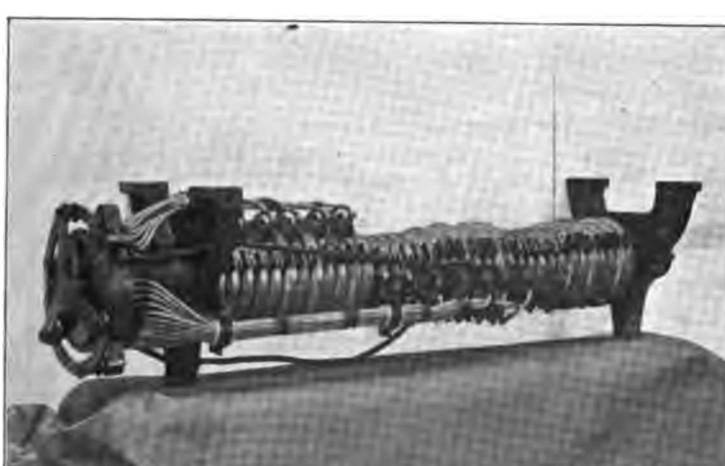


FIG. 11.

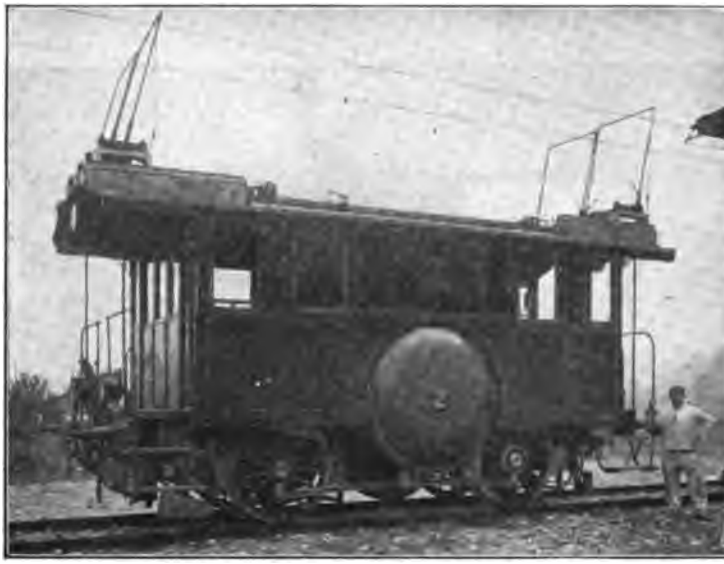


FIG. 12.

rheostats, one into each rotor circuit. Subsequent turning of the controller handle works a combination bevel and chain gear through which three carbon brushes are moved on a sort of commutator attached to each rheostat (see Fig. 11), whereby all the resistance is gradually taken out and the rotors left short-circuited. A second handle on the controller reverses the direction in which the car is going by changing two of the main leads. Each car platform is equipped with two ampere-meters, one

FIG. 13.

voltmeter and a recording tachometer. A Westinghouse brake and an electric lighting and heating installation complete the equipment.

One of the freight locomotives is shown in Figs. 12 and 13. They are designed for a speed of 19½ km. (about 12 miles) per hour, and will haul a weight of 100 tons (not including their own weight) up the steepest grade of 2.5%. The weight of a locomotive complete is 30 tons, equally divided between two axles. Two motors of 150 h.p. each are mounted on a common shaft half way between these two axles and drive by means of a reduction gear first an intermediary axle, and from this axle by means of connecting rods, all four driving wheels. These are 1.23 m. (almost exactly 4 ft.) in diameter. A common rheostat serves for starting both motors and there is a controller on each platform as in the case of the passenger cars. The same measuring instruments are also to be found, as well as a Westinghouse and an additional hand brake.

This railway has now been in successful operation for almost three years. It was equipped by Brown, Boveri & Co., of Baden, Switzerland, as well as the other Swiss lines mentioned. Later on some actual results obtained on this road will be given, but attention is directed first to three experimental lines recently installed for the purpose of ascertaining the conditions met on long trunk lines with higher voltages and very high speeds.

Lecco-Colico-Sondrio-Chiavenna Railway. — In 1901 Ganz & Co. of Budapest finished the electric equipment of what is usually called the Valtellina Railway in the northern part of Italy.

The length of the line from Lecco to Chiavenna is 65 km. (40 miles), the branch from Colico to Sondrio 41 km. (25 miles). The gauge is normal = 1.43 m. The normal speed is 60 km. (37 miles) per hour for passenger trains and 30 km. for freight trains. It is evident that under these conditions it would have been somewhat difficult to handle the traffic with 750 or even 1,000 volts, and it was therefore decided to adopt a higher voltage. Tests made in the Alt-Ofen shipyard near Budapest showed 3,000 volts to be very suitable for the purpose, and this is the line voltage definitely chosen for this road. The power station generates 20,000 volts at 15 cycles per second, 12 transformers of 300 k.w. each, along the line about 10 km. from each other, reduce this to 3,000 volts. For short periods these transformers can give three times their normal output with a 6% drop in voltage. There are two 8 mm. trolley wires, the track serving as a third conductor. The rolling stock shows passenger automobiles weighing 50 tons, and freight locomotives weighing 40 tons each. Both are of the double bogie type, with one motor of 150 h.p. on each of the four driving axles. The motors are mounted direct on hollow shafts on the axles, driving the latter by means of a flexible coupling. For the passenger cars the so-called "cascade" connection is made use of, two of the motors being connected to the 3,000 volts directly, the other two to the 300 volts induced in the rotors of the first two. Thus

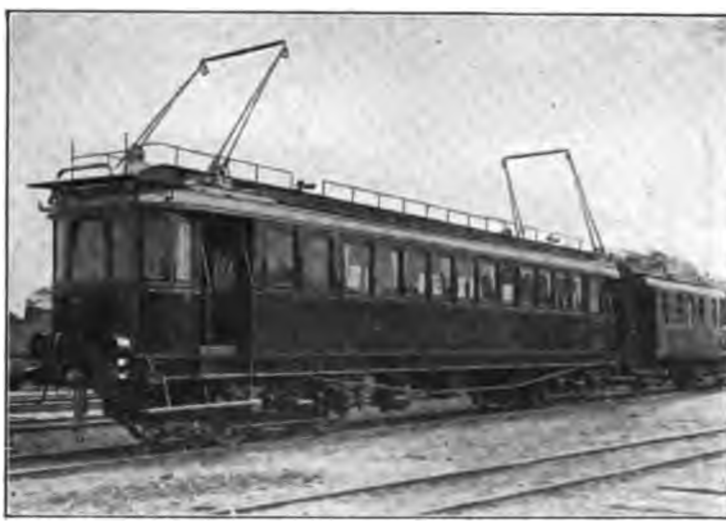


FIG. 14.

half normal speed is obtained and a certain economy in starting. The freight locomotives, however, use resistances only for starting purposes.

Fig. 14 shows one of the passenger cars with a trailer. The contact device is of the roller type, two copper rollers 40 cm. long being separated by a piece of hard wood 12 cm. long, saturated with paraffin under pressure. In the interior of the cars the high tension is carried in iron pipes insulated inside and connected to earth. The current enters the stators of the motors after passing a high tension switch placed in a separate chamber. Thus all possible means have been employed to ensure absolute safety to the passengers. Trial runs have been made on this line but several details seem to need to be perfected, and the line is not yet open for traffic.

Tests at Grosslichterfelde.—Still higher voltages were used by Siemens & Halske in 1899 and 1900 during extensive tests made on the Teltower Road between Grosslichterfelde and Zehlendorf on a specially constructed test track a little over one mile long, normal gauge, with curves of 200, 100 and 40 m. radius. On account of the traffic on this public road the contact line had to be placed on one side of the road and for the same reasons a guard wire net had to be fixed under all wires. The main object of these tests was to find a suitable contact device and the best possible line construction to handle a cur-

FIG. 15.

rent of 10,000 volts and at car speeds up to 60 km. (37 miles).

The first tests were made with a device making contact with the line from above, as shown on Fig. 15. The line wire was fastened to triple petticoat porcelain insulators by means of special brass pieces. The insulators were mounted on wooden cross-arms of different lengths which were hinged to iron poles in such a way as to permit the tension in the wires to be equalized without difficulty. The three wires formed an inclined plane as may clearly be seen from the photograph.

Later the line construction was changed and arranged for making contact from the side. The three wires were placed in a vertical plane with distances of about one yard from one another. The wooden cross-arms were replaced by elliptically curved angle irons provided with a guy wire, to which the insulators were fastened inclined toward the track. The line and the corresponding contact devices are clearly shown in Fig. 16.

In both cases tests were made with line voltages of 750, 2,000

FIG. 16.

and 10,000 volts. The locomotive was fitted with two three-phase induction motors, one on each axle and each for 30 h.p. normal and 120 h.p. maximum output at 650 volts. With 850 volts the output would be increased to 200 h.p. per motor. These motors had interchangeable armatures so that they could be used for 750 or for 2,000 volts directly with the line voltage. For the tests with 10,000 volts on the line, a transformer was installed on the locomotive to transform down to 750 volts. There were two different reduction gears which could be inserted alternatingly, one for 40 km. an hour, the other for 60 km. an hour. The total weight of the locomotive completely equipped was 16 tons.

From the tests made the following results were deduced:

1. It is entirely feasible to use line voltages up to 10,000 volts and the necessary energy could be taken from the line in each case without difficulty.

2. The contact from the side is rather the better of the two.

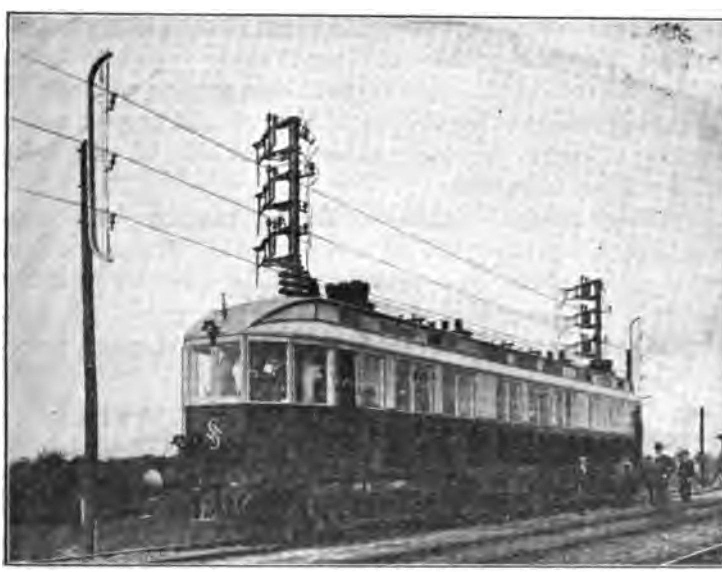


FIG. 17.

The Zossen Railway.—These results were availed of for the tests which are now being made on the normal gauge line from Marienfelde to Zossen, about 15 miles long, where the line voltage is 10,000 volts at 45-50 periods per second and the speeds attempted up to 220 km. (135 miles) an hour.

It would lead too far to go into details regarding these tests which have not yet been completed. Suffice it to say that as far as the electric equipment is concerned, they have been entirely satisfactory. The maximum speed obtained thus far is 160 km. (100 miles) per hour.

Fig. 17 shows one of the cars employed, and it will be noticed that line and contact device are shaped after the models used during the tests carried out on the Teltow road. There are 4 motors per car, each of 250 h.p. normal and 750 h.p. maximum output. The car when completely equipped weighs 90 tons and is designed to take 50 passengers.

Tests on the Burgdorf-Thun Railway.—Following the program laid down at the beginning, some special tests made on the Burgdorf-Thun Railway will be described.

First the overload capacity of the passenger cars was tried. These cars were designed to haul normally a total train weight of 50 tons on all grades at a speed of 39 km. (24 miles) an hour.

A test train was put together to weigh 70 tons total, i. e., 40% overload, and the motors did their work very well indeed, starting on the 2.5% grade without any trouble whatever. If therefore one of the four motors of a car should ever be temporarily out of order, the other three motors will be able to deal with a normal train alone.

In actual service neither the motors nor the transformers show any appreciable rise in temperature. The transformers are, of course, under load for short periods only, say 10 minutes at a time. Their size was therefore evidently not determined by their heating but by the maximum drop in voltage, which in this case was not quite 10%.

Fig. 18 shows in curve form the results of some starting tests made under three different conditions:

(a.) One motor car alone weighing 32 tons,

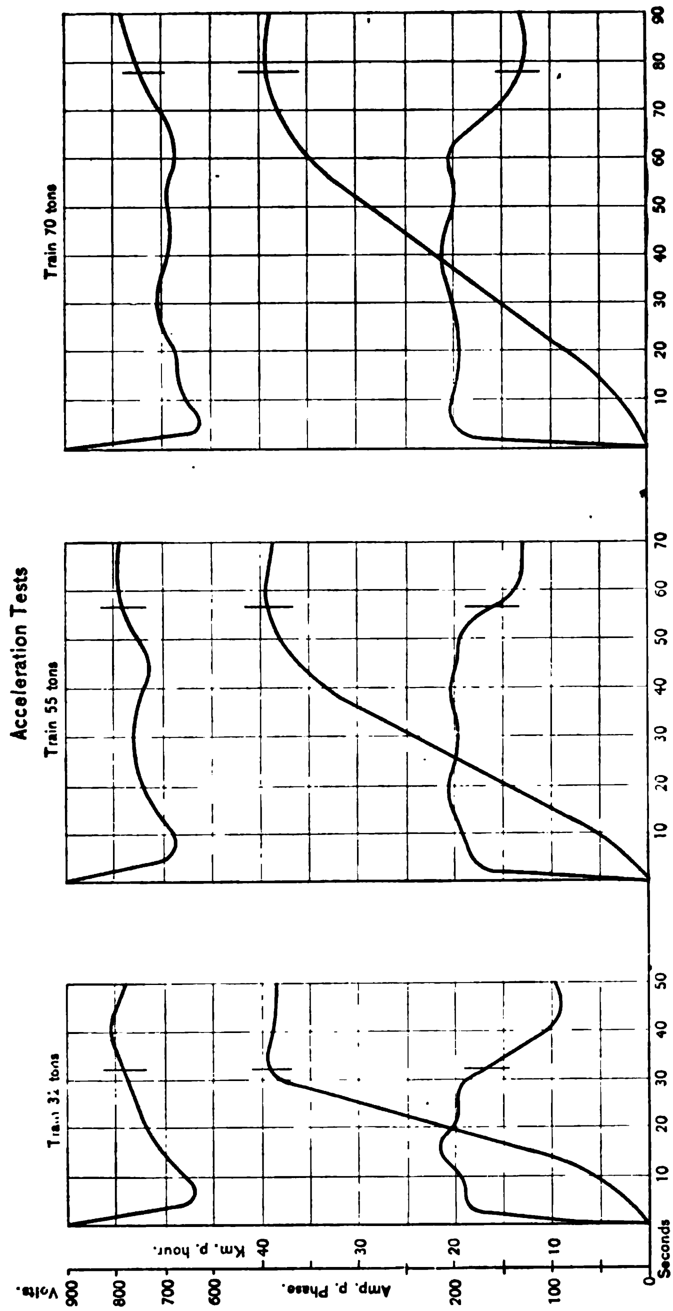
(b.) One motor car hauling 2 trailers, total weight 55 tons.

(c.) One motor car hauling three trailers, total weight 70 tons.

The curves show speed, amperes per phase and volts as functions of time. The tests were made on the level and the controller manipulated so as to keep the current as nearly as possible constant at 200 amperes. This represents actual working conditions.

Readings were taken on the instruments mounted on the car at regular intervals of 5 seconds, the usual employe of the road acting as motorman. The automatic speed record made by the speed indicator corresponded very closely in each case with the curves thus obtained.

It will be found that a weight of 32 tons was brought up to a speed of 24 miles an hour in about 32 seconds, a weight of 55


Acceleration Tests
Train 70 tons
Train 55 tons
Volts.
Amp. p. Phase.
Km. p. hour.
Seconds

tons in about 57 seconds, and a weight of 70 tons in about 78 seconds.

The total energy input up to the point where full speed was reached, was something like 1,600 watt hours in the first case, 3,000 watt hours in the second case and 3,900 watt hours in the third case, or approximately 52, 55 and 56 watt hours per ton respectively, a power factor of 0.8 being used to calculate real energy.

These results appear to compare very favorably with such as have been recently obtained with continuous current motors and this in regard to time of getting up speed as well as in regard to energy consumed during acceleration.

By the use of the series parallel controller, continuous current motors may be made to consume, I believe, as a minimum about 40-45 watt hours per ton under similar conditions, which would be a little less than 80% of the energy consumed by the above alternating current motors. There is, however, this point to be taken into consideration, that the maximum power input in the case of the alternating current motors is not very much above the average input, while in the case of the continuous current motor the energy curve has a very decided point, making the maximum input always more than 50% and often 100% more than the average input. The times given above for getting up full speed are rather better than have been obtained so far with continuous current motors.

Fig. 19 represents some readings taken during a regular time table run of a normal passenger train weighing 50 tons from Walkringen to Konolfingen, viz: up and down over the highest point of the road.

It will be noticed that very severe grades were encountered. The curves show the normal speed up the grade to be about 38 km., on the level stretch on the top about 39 km. and on the down grade about 40 km. or a slip of about 2% both ways.

The amperes curve clearly shows the difference between energy consumed in going up, and energy returned when coming down. Of course the power factors will be different in the two cases, and the real amounts of consumed and returned energy cannot be calculated from this curve. It is, however, interesting to see how the voltage increases on the down grade, thereby clearly indicating that the load is taken off. This test was made with the brakes wide open all the time and the motor resistances were used for starting purposes only.

A further test showed that by inserting resistance in the motors while on the down grade the speed could be increased materially and the speed reached on this occasion was about 44 km. on a down grade of about 1.4%.

Finally a test was made on a fully loaded train which was going up hill on a 2.5% grade. It was suddenly changed to going down. All brakes were left open and yet the train settled on its downward trip at the normal speed of about 40 km.

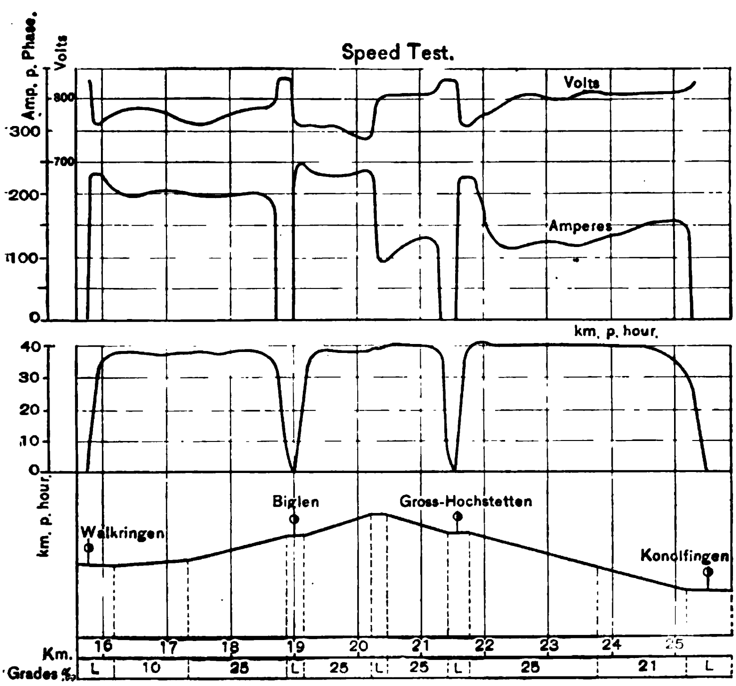


FIG. 19.

which was not exceeded. Then its direction was changed again and the start was made without any difficulty whatever.

Conclusions.—From these tests we may draw some very interesting conclusions.

I shall first sum up the results more especially in regard to the motors and the car equipments, which may be formulated as follows:

1. If properly designed, alternating current motors may be made to start under full load with not more than normal full load running current. They will also start under a considerable

overload. The only condition which has to be strictly observed in the case of alternating current motors is that the drop in the line voltage may not exceed a certain percentage, say 15% to be on the safe side. In this respect the continuous current system is more elastic and a continuous current motor will start with full torque even under very low voltages. In practice there is, however, no reason for allowing excessive drops in the line. Besides it would be easy to install on particularly exposed points transformers giving a somewhat higher secondary voltage in order to increase the torque of the motors in these cases.

2. In regard to acceleration we may say that alternating current motors are well adapted for accelerating quickly and uniformly up to full speed. Compared with continuous current motors they show a somewhat better, viz: shorter, time to get up full speed, a somewhat increased amount of energy consumed during the acceleration and a smaller maximum energy input.

3. During the run we find the speed of the alternating current motor to be practically constant on the level as well as on all grades, as it is dependent practically only on the number of cycles of the generators. This means that alternating current motors must be proportioned so as to be able to draw the maximum weight at normal speed on the maximum grade. Continuous current motors need not have the same output, as it is possible, especially in the case of several motors per car, to give the motor momentarily a greater torque by reducing the speed. This, however, is only feasible within certain limits and actual practice has shown that the gain in weight of motor thus obtained is very small compared with the weight of an alternating current motor running always at the same speed. In most cases it will hardly exceed 10-15%. Besides, as pointed out above, the voltage of the line might be increased at the grades in order to increase the capacity of the alternating current motor.

4. On down grades the alternating current motor acts as a generator returning energy to the line. This recuperation of energy is not only theoretically feasible, but is of actual interest in the case of prolonged down grades where the motors thus automatically brake themselves and where the descending trains greatly relieve the power station. In Siemens & Halske's tests, the alternating current generators were driven by continuous current motors from a storage battery. When the car

was going down grade, energy was returned and the storage battery actually charged. The Swiss mountain lines have installed water resistances to use up the excess of energy made free by descending trains.

5. In a mechanical way the alternating current motor is of course superior to the continuous current motor. The absence of the commutator alone is an advantage. Then the voltage in the rotor may be chosen as low as convenient, which makes the rheostats better and safer. All the Swiss roads which have been operated now between 3 and 4 years, the Lugano Tramways even 7 years, report having had practically no repairs whatever on any parts of the electrical equipment, and none whatever on the motors, which is more than can be said of the usual continuous current equipment.

6. Finally the manipulation of the cars is greatly simplified by the constancy of speed which in this connection is a decided advantage. All the motorman has to do is to start his car and bring it up to speed. The car itself will do the rest until it is stopped by the application of the brake. The concatenated motor control although showing a slightly better efficiency during starting makes the controlling apparatus more complicated and it is therefore preferable in most cases to adhere to the ordinary resistance control, which has really proved to be pretty efficient after all.

Now in regard to the line we find:

7. The increased voltage admissible for alternating current systems reduces the dimensions of the line wires. If carried beyond a certain point the insulation will, however, have to be increased. In cases where the energy used is so large that it cannot be taken off the line at voltages below 1,000 volts, alternating current becomes a necessity. I believe that 100-150 amperes per contact device is just about the maximum permissible, although I know that in some cases, especially in America, as much as 300 amperes have been taken off by one trolley wheel.

8. The transformation of the high voltage alternating currents universally used for transmission on long roads into continuous current means the installation of rotary converter substations. For transformation into alternating currents stationary transformers are used which do not call for any particular attendance and, having no rotating parts, do not show any deterioration from use.

Concluding I might now make the following few general remarks regarding the applicability of the two systems for traction purposes:

Both systems are probably capable of satisfactorily doing the work demanded by any traction problem. I therefore repeat that each case ought to be studied for itself in order to find out which system presents the greater advantages.

Very irregular profile and frequent stops, especially if combined with greatly varying speeds as found for instance in congested city street traffic, make a line generally more suitable for continuous current, while a regular profile, even in the case of steep grades, and long runs between stations, would make it better fitted for alternating currents.

Those cases are rare, however, which allow of an *a priori* decision in this respect, and I believe that a discussion on the merits of the two systems in general is a difficult thing.

What I would like to call your attention to, is the fact that the Burgdorf-Thun Railway answers a whole series of questions relating to the application of three-phase alternating current to electric traction, and proves without doubt the possibility of replacing the present steam locomotives by electrically driven vehicles. This, of course, is of special interest to countries like Switzerland, possessing natural resources in the way of water power, but large coal fields may also be put to better use by erecting electric central stations in their immediate neighborhood and transmitting the energy thus generated electrically to the places where it will be used on the cars.

Zurich, Switzerland, April, 1902.

A paper presented at the Annual Meeting of the American Institute of Electrical Engineers at New York, May 20th, 1902.

A NOVEL COMBINATION OF POLYPHASE MOTORS FOR TRACTION PURPOSES.

BY ERNST DANIELSON.

During the last few years there has been a great deal of discussion as to the possibility of using alternating current motors economically for traction purposes. The result so far obtained seems to be that while these motors may prove successful not only technically but also commercially in special cases, yet as a rule they are inferior to the direct current series motors for general work. The reason for this is that the polyphase motors behave like shunt motors, *i. e.*, operate economically only at a certain speed and that accordingly other speeds are obtained only with a sacrifice in economy. It is true also that the induction motors have other drawbacks, for instance, the wattless currents which necessarily belong to them, but it seems that the advantages which they possess in simplicity and of doing away with sub-stations using rotating machinery, are important enough to compensate for the disadvantage of wattless currents. It has also been pointed out by Mr. Scott at the Buffalo convention when advocating the D. C. motors for electric railway service, that the invention of a speed changing device might change the situation. The author here proposes to deal with an arrangement which makes it possible to obtain economically four different speeds by means of only two motors—an arrangement which it seems will do away with some of the difficulties now experienced in applying the induction motors to railway work.

As is well known the concatenated control of two induction motors consists in connecting the secondary circuit of one to the primary of the other, mechanical connection being arranged so as to make the moving parts of both motors always run at the same speed. In this way a combination is obtained giving a speed corresponding to half of the regular speed of each motor. The torque of each motor will be the same when used single or in concatenated connection. This means that the output of the concatenated combination is only half of the output of the motors, operating independently. If instead of using two similar motors two motors, of different speeds (*i. e.* with a different number of poles) are combined in concatenated connection, a speed is obtained which corresponds to a number of poles equal to the sum of both motors. Suppose a combination of a 6-pole and a 4-pole motor and that the frequency = 50 cycles per second—then three different speeds are possible, viz: the speed of the 4-pole motor alone (the 6-pole motor running idle)

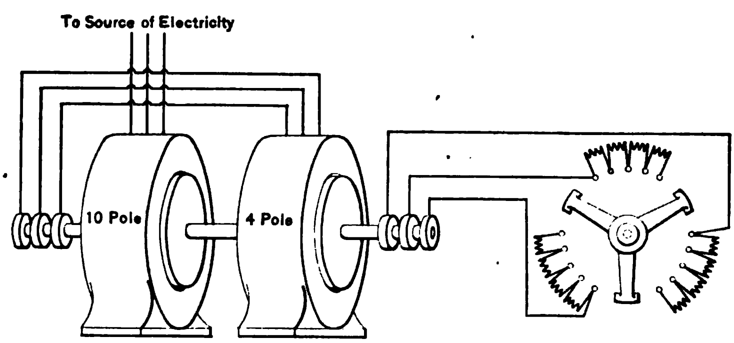


FIG. 1.

= 1500 rev. p. m. (minus slip), the 6-pole motor speed = 1000 rev. p. m. and the combination speed = 600 rev. p. m. If both motors are of the same horse-power, say for instance 50 h.p., it is easy to see that the combination gives also 50 h.p. *By means of this arrangement we have accordingly got a motor capacity of* 50 *h.p. at three different speeds*, 1,500, 1,000 *and* 600 *rev. p. m.*

But it is possible to go still further. When connecting in concatenation we have the possibility of making the connection either so that the torque of both motors works in the same direction or by crossing the leads combining the secondary of the first motor with the primary of the second to get a resultant torque which is the difference between those of the two motors. This arrangement may be called a differential concatenated connection. In order to see the result of this, let us suppose two motors, one with 10 poles and one with four poles, both of the same output, say 50 h.p. each, the rotors of which are mounted on the same shaft (Fig. 1). If now the source of electricity be connected to the stator of the 4-pole motor, and the rotor winding of the same motor be connected to the rotor winding of the 10-pole motor in such a way that the magnetic field in both rotors will revolve in the same direction relatively to their cores —then the torques of both motors will be opposite to each other. As both motors have the same output, then if the torque of the 4 pole motor be called unity, that of the 10-pole motor will be 2 5, accordingly the resulting torque in this case will be 2.5

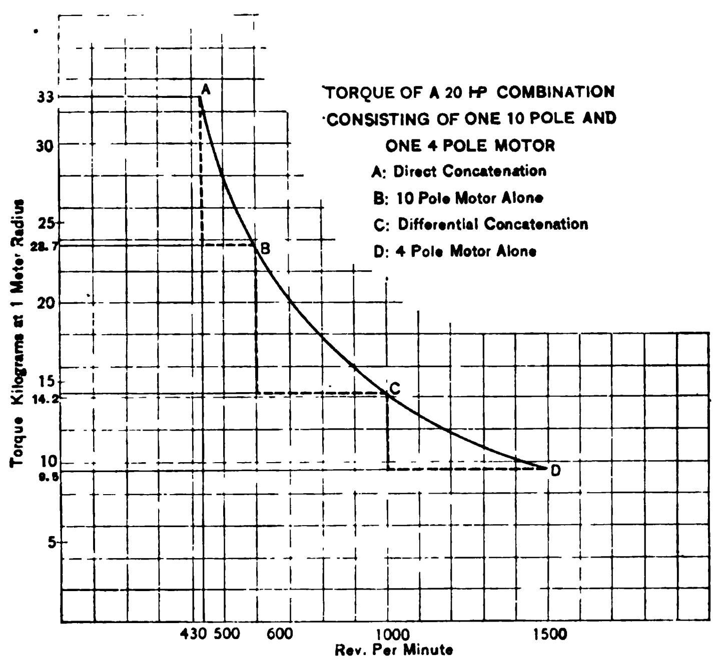


FIG. 2.

$-1=1.5$ and acting in the same direction as that of the 10-pole motor. As the system begins to move, the frequency in the circuit belonging to the rotors increases, whereas the frequency in the stator of the 10-pole motor decreases. Started in the regular way by inserting resistance in the last secondary and gradually cutting it out, the speed comes up until the frequency in the stator winding of the 10-pole motor approaches zero, which will happen when the speed is 1,000 rev. per minute (the frequency is as before assumed $=50$ cycles per second), that is to say we have obtained a motor running at 1000 rev. and with a torque which is represented by 1.5 ; the torque of a 1,500 rev. motor (4-pole) of 50 h.p. being equal to 1. Accordingly the horse-power of this arrangement is still 50. By means of this combination of two motors we can thus obtain the same output under the following conditions: (1). The 4-pole motor alone—the 10-pole running idle—speed 1,500 rev. p. m. (2). Differential concatenation speed = 1,000 rev. p. m. (3). 10-pole motor alone—4-pole motor running idle—speed = 600 rev. p. m. (4). Regular or direct concatenation—speed = 428 rev. p. m. These torques and speeds are graphically represented in Fig. 2, which gives the torque for any of the speeds with regular full load current on a 20 h.p. motor. No attention is however given to the lag which, of course, is considerably

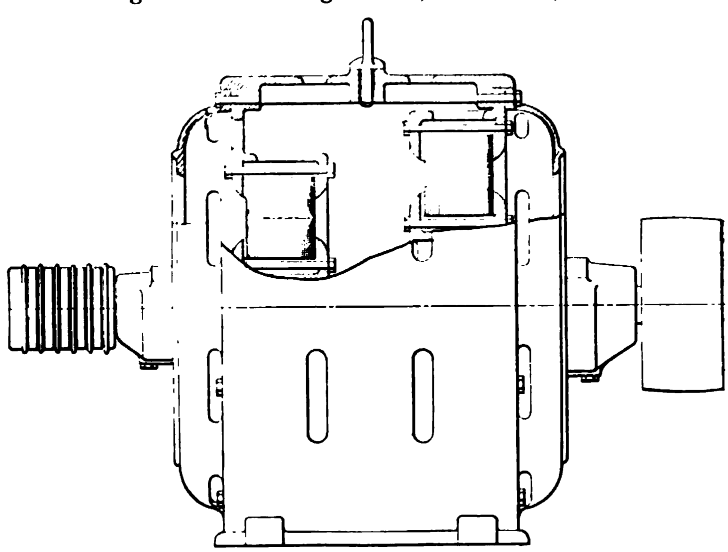


FIG. 3.

greater in the concatenated connection—direct or differential—than with one motor alone.

Fig. 3 shows a small motor built on these principles and which is intended for running tool machinery in a workshop. It is designed with one side 10-pole (large diameter) and the other 4-pole, and accordingly gives the same synchronous speeds 428, 600, 1,000, 1,500.

It goes without saying that if gearing of some kind be used, the motors need not have different numbers of poles; for instance if both motors are identical and are geared to the same shaft so that one gives a speed of 0.617 of what the other gives, then the speeds which are obtainable form a geometrical series the ratio of which is 0.617; that is to say it is possible to obtain four different speeds each of which is 0.617 of the one which is nearest higher.

Before investigating how this method can be applied for railway motors there should be pointed out some features which are interesting in the differential concatenation. As has been first noticed by Steinmetz a system of two equal motors in concatenated connection can operate at two different speeds, one of them being practically the same as if the motors were driven independently, that is to say, double the speed of the concatenated speed proper. With a system of two unequal motors the same phenomenon appears: a concatenated pair consisting of one 6-pole and one 4-pole motor can also run—with 6-pole speed if the 6-pole motor is connected to the source of electricity and with 4-pole speed if the 4-pole motor is nearest the source. In all these cases there is no risk of obtaining these secondary speeds instead of the one which is desired, because the desired concatenated speed is always lower than the secondary speeds. Thus when the desired speed is reached the motor cannot of itself get higher.

With the differential concatenation the matter is a little more complicated. Above, when describing the differential method we havé for the sake of simplicity assumed that the motor with the fewer number of poles was used as the primary motor, *i. e.* connected to the generator circuit. In this case the secondary speed which is obtainable is the speed of the prime motor itself and *in opposite direction to the differential concatenated speed proper*. Consequently there is not even here when starting any possibility of getting the wrong speed instead of that desired. But suppose that the 10-pole motor had been the primary motor. Evidently the starting would take place in the same way as before, but when the speed of 600 rev. was reached the motor would not get up any higher but would continue to run and develop torque as soon as the speed fell a little short of 600 rev. p. m. That, however, also with this connection the differential speed of 1000 rev. (minus slip) works just as well as with the other connection, will be clear from the following:

Suppose that the connections are exactly as before described for differential concatenation only, with the difference that the generator is connected to the stator winding of the 10-pole motor and the rheostat to the stator of the 4-pole motor. If now the rotating field in the 10-pole motor rotates clockwise and by some external force the machine is speeded up to say 970 rev. p. m. clockwise, what will happen? The magnetic field in the 10-pole rotor moves relatively to the iron core with a speed of $600-970=-370$ rev. p. m., and its direction of rotation accordingly is counter clockwise in the iron. The relative speed of the magnetic field in the 4-pole rotor then is $-370\times 10/4$, also counter clockwise. The absolute speed therein is clockwise and equals $970-370\times 10/4=45$ rev. p.m. Evidently when this field revolves clockwise—in the same direction as the movement, the 4-pole motor acts as a generator. The action is exactly the same as that of any induction motor with its primary element rotating, running at a higher speed than synchronism. Now the currents from this generator are used to speed up the 10-pole motor. when at the same time evidently the torque required for running the 4-pole generator part of the system is subtracted from the 10-pole motor part. The case is analogous to this: Take a regular induction motor and connect not only its primary but also its secondary to the source of electricity. Then with proper connections we can obtain twice the regular synchronous speed of the motor.

That the 10-pole part of the motor system in this case acts as a motor and not as a generator may be proved in this way. When in an induction motor the speed of the rotor falls short of the synchronous speed, then the current induced in the secondary winding is nearly in phase with the e. m. f. that produces it, that is to say the rotor winding carries what might be called a generator current. If then the rotor increases its speed so as to exceed that of the revolving field of the primary then the electromotive force induced in the secondary part (rotor winding) would change its phase by 180° in relation to the magnetic field; hence it is clear that the current in the secondary winding now has to be in opposition to the phase of the e. m.f. that is to say: in order to make an induction motor work as a motor above synchronism its secondary winding should not itself generate its current but a current has to be let into it against its own e. m. f. This is exactly what happens in one motor here as we have pointed out that the 4-pole side acts as a generator and then of course the e. m. f. from the 10-pole rotor acts as a counter e. m. f.

On account of this we find that also with this connection the motor will act as a motor with $10-4=6$ poles just the same, but that it will not by itself get up to the right speed but has to be speeded up by some outside force.

Having now described the methods of the differential concatenation in combination with the direct one the next question is this: What advantage can be derived from this arrangement for railway work. Immediately it will be clear to a student of these matters that one advantage of an important nature is the possibility of using economically four different speeds instead of two. (As a matter of fact the method of getting three different speeds has been known for some time but so far as the writer is aware it has not yet been used for traction purposes). When running over a road with considerable grades we now have the possibility of working the motors at different torques

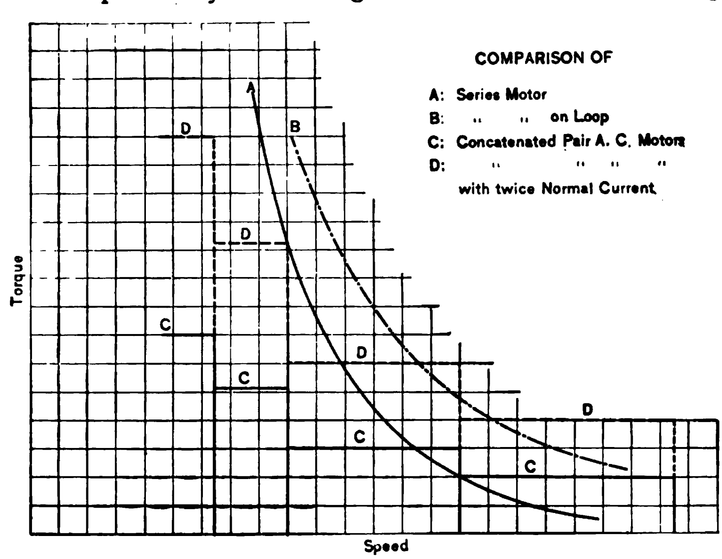


FIG. 4.

corresponding to the different speeds and still have the same output of the motors, *i. e.*, a practically constant current. As is well known this is not the case with the series motor. When this motor increases its speed, not only the torque but also the output becomes less, and can be increased only by cutting out part of the field, an arrangement which is less satisfactory as it often causes a liability of sparking. With the methods described above on the contrary it is possible over almost the whole range to increase the torque above the normal, if that should be considered desirable—for instance in order to make up for lost time. This is shown graphically in Fig. 4, which shows a curve of torque and speed for a series motor and for a combination of polyphase motors. While the D. C. motor cannot at higher speeds develop torque above the curve "on loop," the A. C. motors can at will momentarily develop anything up to the dotted line. When using this system the task of the motorman will consist only in handling the controller so as to keep the current at a certain normal value not only when accelerating but also when running.

There is, however, one question more, and which is really fully as important as those already dealt with, viz: how is the economy in starting. This is the vital point for a considerable part of traction work projected just now. In order to see the result of the 3 and 4-speed arrangements in this direction, it is necessary to choose special cases—different combinations giving different economy. As an example take for the 4-speed system two motors, one giving 2.5 times the speed of the other; for the 3-speed arrangement, two motors, one giving 50% more speed than the other, and compare the results of these combinations with the regular concatenated connection of two similar motors with the single motor and the D. C. series motor as to economy in starting. In order to find the relative economy we shall first consider the loss in secondary resistance outside the motors, that is to say, the loss if there were no losses in the motors themselves. When such an induction motor is brought up to full speed from standing still and with a constant torque, the input is exactly twice the output, that is to say, the loss in secondary resistance is equal to the amount of useful work. Generally if an induction motor with no losses in itself be brought up from a speed $= n$ up to full speed $= 1$ with constant torque the ratio of input to output is $= \frac{2}{n+1}.$

Applying this formula to the different cases we find, if the useful work is unity, the input in electrical energy in the different cases:

(1) *The single motor* $\frac{2}{0+1} \times 1 = 2.$

(2) *Two similar motors; concatenated connection used up to half of normal speed:* Energy developed by motor up to half speed $= \frac{1}{4}$; accordingly

$$\frac{2}{0+1} \times \frac{1}{4} + \frac{2}{0.5+1} \times \frac{3}{8} = 1\frac{1}{2}$$

(3) *Two motors with relative speeds* 1 : 1.5; *giving three speeds* 0.4 ; 0.667 ; 1.

Energy stored up at these three speeds = 0.16; 0.444; 1 accordingly

$$\frac{2}{0+1} \times 0.16 + \frac{2}{\frac{0.4}{0.67}+1} \times (0.44 - 0.16) + \frac{2}{0.67+1} \times$$

$$(1 - 0.444) = 0.32 + 0.355 + 0.667 = 1.342.$$

(4) *Two motors with relative speeds* 1; 2.5 *giving four speeds* =0.286; 0.4; 0.667; 1.

Energies corresponding to these speeds
=0.082; 0.16; 0.444; 1.

Input accordingly

$$= \frac{2}{0+1} \times 0.082 + \frac{2}{\frac{0.286}{0.4}+1} \times (0.16 - 0.082) + \frac{2}{\frac{0.4}{0.67}+1} \times$$

$$(0.444 - 0.16) + \frac{2}{0.67+1}(1 - 0.444) = 0.164 + 0.091 +$$

$$+ 0.355 + 0.667 = 1.277.$$

In order to compare these results with the economy in starting with D. C. motors we assume a series motor having no losses in itself; then the economy, when starting, is depending on at what lowest speed we can obtain the full counter e. m. f. An assumption which corresponds fairly well to regular good engineering is, that the full e. m. f. is reached at a speed of $\frac{2}{3}$ to $\frac{3}{4}$ of the full speed. When connecting the motors in series this will accordingly correspond to a speed of $\frac{1}{3}$ or $\frac{3}{8}$ of full speed when the changing over from series connection to parallel is accomplished. Using the same formula as before which is here equally applicable we find input in electrical energy in order to obtain a useful work of unity:

(1) *Full voltage rendered by the motors at* $\frac{2}{3}$ *of full speed.*
Energy required =

$$\frac{2}{0+1} \times \frac{1}{9} + \frac{2}{\frac{0.333}{0.667}+1} \times \left(\frac{4}{9} - \frac{1}{9}\right) + \left(1 - \frac{4}{9}\right) =$$

$$= 0.222 + 0.444 + 0.555 = 1.222.$$

(2) *Full voltage rendered by the motors at* $\frac{3}{4}$ *of full speed.*
Energy required =

$$\frac{2}{0+1} \times \frac{9}{64} + \frac{2}{\frac{0.375}{0.75}+1} \times \left(\frac{9}{16} - \frac{9}{64}\right) + \left(1 - \frac{9}{16}\right) =$$

$$0.281 + 0.562 + 0.437 = 1.281.$$

Comparing these results we find that neglecting the losses in the motors themselves, the economy in starting. when using the combination of direct and differential concatenated connection, may be made very nearly the same as in direct current work, and that the three-speed concatenated connection gives an input of something like 6 to 7% more, the regular concatenated connection with 2 similar motors an input of about 20% more than the direct current and 4-speed alternating system and finally the single alternating motor an input of about 75% more.

Now taking into consideration the losses of the motors themselves in order to get a really fair comparison of the relative merits we may assume the efficiency of the series motor and an induction motor at full load the same, say 92%—the efficiency of two motors in concatenation will then come to something like 82% (or even 84 with a low periodicity, say 25 cycles). Let us, however, assume only 82%. If this is taken into consideration and the time during which the motors work with their different efficiencies, in different connections is also considered, we get the following results:

Electrical energy for obtaining unity useful work in starting up to full speed

(1) *The single alternating motor* 2.17

(2) *Two similar motors: concatenated connection used up to half of normal speed* = 1.72.

(3) *Two motors with relative speeds* 1 : 1.5, *giving three speeds* 0.4 : 0.667 : 1 = 1.51.

(4) *Two motors with relative speeds* 1 : 2.5, *giving four speeds:* 0.286 : 0.4 : 0.667 : 1 = 1.45.

(5) *Continuous current series motors operating in series up to* $\frac{1}{3}$ *of full speed and resistance entirely cut out at* $\frac{2}{3}$ *of full speed* = 1.33.

(6) *Continuous current series motors operating in series up to* $\frac{3}{8}$ *of full speed and resistance entirely cut out at* $\frac{3}{4}$ *of full speed* = 1.4.

In these calculations some factors of minor importance are neglected. Considering for instance the iron losses in the secondary of the induction motors when accelerating would make the figures slightly more favorable to the D. C. series motors. On the contrary, it should be observed that there is an approximation in favor of the series motor to assume that connected in series they get up to fully half of the speed, when connected in multiple with same current. These approximations, however, will have very small influence on the results obtained.

Now taking into consideration the energy which can be returned to the line by means of the A. C. motors it is evident that also in this respect an advantage is obtained over the simple concatenated connection.

Taking the three-speed combination we find it possible to brake electrically and return energy to about 0.43 of the full speed and with the four-speed combination down to about 0.31 of the same.

Theoretically it would be possible, when braking electrically, with the three and four-speed arrangements to do it in steps, but as this would mean a slower stopping, reference is here only made to applying at once the full braking torque corresponding to the concatenation giving the smallest speed.

(1) *Single motor—no energy.*

(2) *Two similar motors.*

Braking down to about 0.54% speed. Energy restored when braking from speed $= n$ down to the least possible $= n_1$ with that connection $= \frac{2\,n_1}{n_1 + n} \times$ efficiency of motor acting as generator $\times$ energy taken from moving masses.

When using motors in concatenation for braking it must be borne in mind that it is not generally possible to obtain a negative torque until the speed has come down to a certain percentage of the full speed.[1] This percentage is dependent on the resistances of the conductors and may vary considerably. For the purpose of getting a comparison it is here assumed that the electrical braking can begin at a speed of 0.9 of the synchronous speed.

In this case energy accordingly is taken from moving masses from 0.9 down to 0.54 of full speed. Accordingly if efficiency be taken $= 0.82$

$$(0.81—0.29)\times\frac{2\times0.54}{0.54+0.9}\times0.82 = 0.32$$

(3) *Three-speed motors as before.* When braking, connect immediately in concatenation so as to be able to use the same connection down to 0.43 of full speed.

1. With the three and four-speed arrangements it can be obtained but involves more complication.

$$\text{Energy restored} = (0.81-0.185) \times \frac{2\times0.43}{0.43+0.9} \times 0.82 = 0.33$$

(4) *Four-speed motors as before.* When braking connect directly for being able to brake down to a speed of 0.31 of full speed.

$$\text{Energy restored} = (0.81-0.096) \times \frac{2\times0.31}{0.31+0.9} \times 0.82 = 0.3$$

The results so far obtained would correspond to reality in such cases where gearing is not made use of; if gearing is used, the loss therein should be taken into consideration. This loss may generally be estimated at about 5%; it must however, be borne in mind that in the case of differential concatenation it may amount to somewhat more, since the power transmitted through the gearing really is more than the resultant power. In the

RELATIVE AMOUNT OF ENERGY CONSUMED.

	Accelerating only.		Accelerating and Electrically Braking.	
	Without gearing.	With gearing.	Without gearing.	With gearing.
D. C. Motor, resistance entirely cut out at 2/3 full speed	1.33	1.4	1.33	1.4
D. C. Motor, resistance entirely cut out at ¾ full speed	1.4	1.48	1.4	1.48
A. C. Motor, simple	2.17	2.29	2.17	2.29
A. C. Motors regular concatenated connection	1.68	1.77	1.36	1.47
A. C. Motors, three speeds: 0.4 : 0.67 : 1	1.5	1.58	1.17	1.27
A. C. Motors four speeds: 0.285 : 0.4 : 0.67 : 1	1.45	1.52	1.15	1.24

table below where the results are brought together this increased loss is, however, neglected. The table gives a comparison of the different systems as to input, the motors for starting up to full speed and electrically braking down as far as possible.

Admitting that the polyphase motor as a rule is fully as efficient as the series D. C. motor, it may be considered that when working on an even road the difference in energy consumption will be negligible, then it would appear that by using the four-speed arrangements of concatenated connection it would be possible to get a more economical method of working electric roads than by means of the D. C. system with series motors. Considering at the same time that for greater distances the electric energy has to be generated as alternating current and then transformed into direct in converter stations, whereas with polyphase motors on the cars simply static transformers can be used giving a difference in loss of at least 5% to 7% in favor of the alternating current motors, the comparison comes out still more in favor of these. An advantage also for them is that there is no need for high voltage in the rotating parts of the motors; the rotor windings may be arranged for any desired voltage thus giving the designer full liberty to choose this so as to get the most convenient winding.

The author is fully aware of the drawbacks inherent to the alternating system such as the necessity of using a double trolley, the lag, etc., and admits that in many cases this system is entirely out of question, for instance, only on account of the double trolley, but for elevated roads and for underground work this matter hardly comes into consideration, and in many other cases the drawbacks of the alternating system will probably be more than balanced by its greater economy.

One thing more should be mentioned. Probably it will be pointed out that there will be difficulties introduced by making one of the motors of 2.5 times the torque of the other. To this the author would reply that the best solution probably in many cases will be to connect in concatenation one motor with two or three others in parallel—for instance with a locomotive with four axles, have three of the motors of a slower running type than the fourth, and of a current carrying capacity something like ⅓ of this one. The same arrangement could be used for an ordinary double-truck car with four motors. For cars with only two axles the best arrangement will probably be with only three-speed connection, and then there will be very little difficulty—the difference in torque of the two motors not being so considerable.

WESTERAS, SWEDEN, Oct. 25, 1901.

Discussion.

President Steinmetz:—I may say in regard to Mr. de Muralt's paper, I heartily endorse his statement that we cannot draw general broad conclusions regarding the superiority of one type of motor or the other type of motor, but that each individual railway case has to be considered separately on its merits and investigated, before deciding whether an alternating or continuous current motor is preferable for that particular purpose. For many years the alternating current motor has been developed here in the United States, to such a point that we could perfectly trust it to do the work of running the trolley car, or propelling the railway train, and three-phase induction railway motors have been operated for the last eight years .

By all the better engineers, every individual case has been considered on its merits and has been carefully investigated, as those railway engineers who are present can tell us, to determine whether continuous current or alternating current is preferable, and I hope that in the near future we may see some alternating current railway plants go into operation, although I am sorry to say that thus far there has been no case found showing sufficient superiority for the alternating current induction motor to warrant its installation. I would like to call, however, on Mr. Mailloux, to lead the discussion. Mr. Mailloux, as you all know, has given this matter very great attention and has been in Europe to study the various three-phase plants, and I understand when he came back from there he was very enthusiastic regarding the desirability of a polyphase induction motor for electric railway work. I call on Mr. Mailloux.

Mr. C. O. Mailloux:—Mr. President and Gentlemen: I was hoping that somebody else would open this discussion; I came to listen rather than to speak. I think that I ought to correct the President. I believe I remarked at the Buffalo Convention that when I returned from Europe I was very highly saturated with the alternating current feeling, but that I afterward became demagnetized to some extent, and those who participated in the Buffalo discussion will remember that I showed proofs of the fact that I was somewhat demagnetized by insisting rather strongly on the cases where the alternating current motor was not particularly suited. I have had the pleasure of seeing, examining and riding on nearly all of the electric railroads which are mentioned in this paper.

I was quite struck with the Stansstad-Engelberg road and with the Burgdorf-Thun, as representing examples of what I might call real steam railroading conditions to some extent; more perhaps, by the size of the cars and the peculiar traffic conditions under which they operate. More especially is this true in the case of the Burgdorf-Thun railroad, where they operate trains of two or three cars and apparently handle them exactly under ordinary steam railroad conditions. But there is one thing that impressed us as Americans, and that was the time required in acceleration. In this connection I must differ radically with Mr. de Muralt in regard to the conclusions that he mentions on pages 434 and 436, as to the rate of acceleration. It is certain that I did not observe any rates of acceleration such as are quite familiar to us in practice in this country. Moreover, the curves which he gives on page 433, as well as the figures which he cites, do not indicate it. He states on page 432 that a 32-ton car was brought to a speed of 24 miles an hour in about 32 seconds. We would scarcely call that acceleration at all here. It is only three-quarters of a mile per hour per second. It is good enough for steam railroad conditions, but it certainly is not what is necessary and essential for good electric railroad conditions. We think that acceleration might be called acceleration when we reach one mile, and it begins to look interesting when we have one-and-a-half or two miles per hour per second. On many street railway lines, like the Broadway cars here, we will find the rate of acceleration going up to three or four miles per hour per second. I will admit that then it begins to become too interesting and to become uncomfortable. At the same time there is a great difference between one mile per hour per second and two-and-a-half or three.

I think the paper is excellently written and gives a very intelligent resumé of the work which has been done there. The illustrations themselves are especially interesting, because they give one an idea of how things look. The data which the author has given are all very useful to the engineer, and really the only conclusion in which I must disagree with him, is in relation to acceleration. That is, however, a very vital point, which discriminates against the use of the alternating current in many cases in this country. In fact, in most cases where the alternating current has been considered and has had to be set aside, it has been due to the fact that the cost and the difficulty of acceleration with the alternating current motor are too great. It is in many cases not a question of cost, but a matter of physical possibility or impossibility, as the case may be. In the discussion at Buffalo I think I went quite fully into the differences between the two kinds of motors, and I considered the reasons why it is not possible to obtain as rapid acceleration with the alternating current motor as with the direct current motor in the present state of the art; hence I do not think it is necessary to repeat them here. In substance it is due to the fact that while the alternating current motor is limited in the maximum torque which it can produce, which slightly exceeds twice or two-and-a-half times the running torque, yet, with the direct current motor we can obtain 4, 5, 6, 7 and even 10 times the running torque. That is the physical principle which lies at the bottom of the whole matter. It is really the thing which enables us to accelerate faster with direct current motors; and where the stops are at all frequent, where the schedule speed is at all high, we find it necessary to reject, at least in the present state of the art, the alternating current motor. The Burgdorf-Thun line is especially well suited to the alternating current, because the schedule speed is not so very high, the distances between stations are relatively long, the stops are relatively few and the headway is large; all these being conditions which favor that system. In this country when we begin to do transcontinental business with electric railroads, then will the day of the alternating current motor come. When we pass from the purely passenger railroad traffic problems to those which border upon the same service conditions or which are intended to comply with the same service conditions as the so-called steam railroads; then we shall, I think, of necessity have to look to the alternating current motor, because of the many advantages it possesses, which advantages have been quite clearly set forth by the author in his paper. There are many cases to-day in this country where railroad engineers are confronted with problems whose solution they hesitate to undertake because the requirements are such that they really think it desirable to have the qualities of both kinds of motors. In other words, either the art has not advanced far enough, or else the requirements have not changed enough to determine a definite preference for one against the other. This is particularly the case with steam railroads that have through or long-distance traffic and that have also local or suburban traffic. The two parts of their service represent different problems, and it has been found so far that the two are incompatible with each other in so far as they cannot be solved by the same means. The local passenger traffic, the suburban business, usually dictates—I use the word advisedly—the use of the direct current motor, while, on the other hand, the through or long-distance passenger traffic points quite strongly toward the alternating current system. Consequently, either we shall be compelled to use both systems, at first, when we begin to invade the steam railroad field in earnest, or else we must perfect the alternating current system still further, so that it alone may, perhaps, be enabled to fulfil the requirements of both problems successfully and satisfactorily.

I was greatly interested in the paper of Mr. Danielson, which I think is very suggestive of what might be expected in the evolution of methods of using the alternating current motor. I have myself given the matter a great deal of thought, feeling that something ought to be done in that direction. I have myself sought to attain the same result in a different manner, such as by using two or more sets of polar windings having different numbers of poles, in the same stator frame, though in that case there are difficulties in construction. But the idea is substantially the same, and like Mr. Danielson's, it admits of a much greater elasticity in the range of speed and the control of efficiency, as well as the starting torques obtainable, than is possible by the present method, including the ordinary method with rotor resistance, or the method of concatenated or cascade connection.

I very much hope that more will be done, that others will devote thought to this subject and that we shall in a very short time discover many other useful and ingenious methods of enabling us to accomplish with the alternating current motor that which we now find we can do only with the direct current motor.

As I said at the beginning, I have become somewhat demagnetized in my enthusiasm. At the same time I cannot help feeling that there is a great future for the alternating current motor, and I look forward to its evolution and development, and I expect much more from it than has been accomplished hitherto, it being my conviction that it must accomplish a great deal more before it can be looked upon as a satisfactory, all round, general solution of the problem.

MR. HENRY G. STOTT:—I was very much interested in the details of the 10,000-volt trolley line. I think if the trolley did not make very good contact and an arc occurred, there would be a very good opportunity for short-circuit. Do such conditions ever arise? That is to say, assuming the lower trolley contact is imperfect, the arc would certainly rise and strike other wires. Another point that occurred to me was in comparing the method of operating trains with direct current, the number of substations necessary with alternating current work. Here apparently it is necessary, for the sake of keeping the drop down to 10 or 15 per cent., to have a sub-station every three or four miles. In our practice, rotary stations are usually placed not more frequently than from six to ten miles, which would in itself be a considerable investment.

The photographs show the regular Siemens type of horned lightning arrester. Under conditions in this country, this device would last just about one discharge, and I would like to learn of the experience abroad.

PRESIDENT STEINMETZ:—I may say, that considering these European plants, it is interesting to compare somewhat the magnitude of the problems solved there, with American electric railway practice; on the Gornergrat railway the power of the locomotive is 180 h.p. That is very little more than in an ordinary trolley car in New York City, of which hundreds are running. If we turn to the Burgdorf-Thun railway, which is operating under steam railway conditions, we see that even in acceleration the current maximum is 200 amperes at about 750 volts, which corresponds to something like a little over 400 amperes at 500 volts. I have seen an ordinary interurban single trolley car when climbing up a long grade run with over 800 amperes for a considerable period. That is nearly twice the power which the whole Burgdorf-Thun railway, under steam railway conditions, takes for acceleration. For instance, on the trolley road between Schenectady and Albany, running single cars, fairly large cars indeed, the total motor capacity per car is four 50 h.p. motors, or 200 h.p. rated capacity, which is more than the Jungfrau locomotive. In climbing the long grades which we have to mount, the car takes over 800 amperes, by a single trolley wheel. The construction which is customary in Europe but not in this country, is the long roller trolley, which has the disadvantage that it must be operated in an almost vertical position. That means that the trolley wire must be at an approximately constant distance from the track, and this is not feasible here. We have to cross steam railroads where the trolley wire has to be raised very high, and we have to cross under roads and viaducts where the trolley wire has to be lowered, so we must have a trolley construction where the trolley can receive current from the wire irrespective of the height of the latter. That makes this European trolley construction impracticable. As soon as we come to a trolley pole on a very small angle from the horizontal, or the ordinary trolley construction, it is almost impracticable to use more than one trolley at high speeds, 30, 40 or 50 miles per hour, without danger of destroying the overhead construction every time the trolley jumps the wire at speed. That is a great disadvantage in any polyphase motor, where we must have at least two trolley wires.

Mr. de Muralt's paper is extremely interesting, as I said before, in that it brings out the necessity of considering each individual case on its special merits and also that it shows that three-phase railways can be operated successfully for years without any difficulty from breaking down. However, when considering continuous current and three-phase current, what we have to determine is, does the three-phase induction motor in the particular case offer sufficient advantage over the continuous current system to compensate for the very great disadvantages in the induction motor in railway work.

One disadvantage is the necessity of using more than one trolley pole, which means that with overhead construction the problem becomes very difficult at higher speeds. A further great objection to the present type of induction motor is the speed limit, that it is limited to synchronous speed. In consequence thereof, you cannot get the benefit of the higher speeds which the continuous current motor can reach on level tracks. It is impossibile to make up time, where you have to stop a number of times or where you have an unusually large load, or you have to provide in your schedule that the synchronous speed is very much in excess of the schedule speed, which means low efficiency in operation. Furthermore, the fluctuations in load are necessarily much greater, because you climb hills at the same rate as you run on the level track, while the continuous current motor slows down on a hill, and so saves power. The Burgdorf-Thun motor at 40 per cent. overload starts successfully on a 2½ per cent. grade. That would not at all suffice for our railway practice. It may happen that a train gets stalled on a grade greater than 2½ per cent., say 5 per cent. or 8 per cent. grade, and has to wait for the next trolley car or train to rescue it by pushing it ahead, and that means you have to start from rest at a much greater grade than 2½ per cent., and at the same time to push a disabled car. That is an overload which is about three or four times the ordinary load the trolley car has to carry.

The general experience in designing a three-phase induction motor railway plant and a continuous current railway plant, is that in continuous current line construction you have to figure on the average drop of voltage in the line, because the drop of voltage in the line affects only the speed and the efficiency, and not the available torque, and in this case only the average drop comes in and excessive drop for a limited time only is not objectionable, since the schedule speed is not lowered seriously by the excessive drop of voltage occurring at some far distant point, by two cars starting on a grade or anything of that kind. In an induction motor proposition, however, you have to calculate the line construction for the maximum drop of potential which may occur in emergencies, because the motor torque goes down with the square of the voltage, and you must under any conditions be sure that even at the maximum drop of voltage, the car is able to start on a grade with an overload, and there we find in practice, especially when considering the lagging current and the drop of voltage due thereto, that the induction motor is at a very serious disadvantage compared with the continuous current series motor, even considering the use of a much higher voltage for the former. Usually, also, the transformer capacity required with an induction motor railway, even allowing for temporary excessive overloads of the transformer, is very much in excess of the generator capacity and the maximum load of the system.

In general, the direction of electric railroad development here is toward higher schedule speeds and more frequent stops, and also interlinkage with the urban systems, so that the same car runs between cities and through cities, and this requires a type of motor for interurban service which can operate on existing city lines. That is very much against the induction motor.

However, the main field of the induction motor would be where you come to a traffic so infrequent that you cannot reach it without going to a very high voltage on the trolley line, 3,000 or more, and where you have your own right of way, moderate speeds, and a very long distance with very few stops. There the three-phase induction motor may possibly compete successfully with the continuous current motor, also on roads where extremely high speeds are reached on your own right of way, 100 miles or 150 miles per hour; and furthermore, in freight traffic over mountain ranges, for instance, to pick up a heavy freight train or coal train at the foot of a mountain, and instead of breaking it into pieces and putting in pushing locomotives, to pick it up by a powerful electrical locomotive, pull it up the mountain range and let it go down again on the other side, while it returns power to the line. There the induction motor would be decidedly superior to the continuous current motor by returning power to the line. You could do it there, because you naturally operate at low speed, so that you can go beyond synchronism on a downgrade without danger of the train getting away from you. In ordinary railway service, 40 to 50 miles an hour on level track, that is with a synchronous speed of the induction motor at least 40 to 60 miles an hour, you can be sure that it will hardly be possible to run on the motor brake, and going down hill you cannot permit the speed to be high enough to return power.

Now, as I said before, I hope to see in the not distant future, some individual cases where the induction motor is suitable. I may say, however, that if anybody ever developed an alternating current motor of the same characteristics as the continuous current series motor, that is the single phase motor, which has no limiting speed but a torque, which is a maximum in starting and which decreases with the increasing speed, then this alternating current motor would be the motor for railways, even if the efficiency and power factor should not be very high.

MR. W. N. SMITH:—I would like to ask the author what was the average headway or the average distance between stops on this Burgdorf-Thun line, with trains in regular service; also, what is the average drop in voltage which is found to result in ordinary practice, and what has been found to be the lowest practicable drop under the conditions at which that road operates.

In the case of that road or any similar road in Europe, has the use of the rails as one leg of an alternating three-phase circuit been found to unbalance appreciably the circuit, or introduce any difficulties whatever, due to the fact that the conductor is iron and is liable to introduce inductive influences that do not exist in copper trolley wires?

Another question is as to the durability of those long roller trolleys compared with the life of the wheels in use in this country. I suppose the average life of a trolley wheel properly cared for might be taken as 5,000 miles in this country and perhaps more. I have known of their running that mileage.

PRESIDENT STEINMETZ:—I would like to add here another question, whether Mr. de Muralt can give us some information regarding the life of a trolley wire; whether the use of this roller contact increases or reduces the life of the trolley wire. Gradually the trolley wire is worn down, and I have seen from some city roads where there was very heavy traffic, some pieces of wire worn down about 40% of the section until broken. I believe two million cars with their trolleys had passed along that wire before it was so worn and broke.

MR. W. J. HAMMER:—I would like to ask Mr. de Muralt a question regarding the Zossen Railway.

I had the pleasure of making a personal inspection of all the roads (with one exception) mentioned in his paper, and had the honor of presenting the results of my investigations in a paper[1]

[1] "Important European Electrical and Engineering Developments at the Close of the Nineteenth Century."—TRANSACTIONS. vol. xviii. p.47.

before the INSTITUTE at its 151st meeting on February 29, 1901.

If you will refer to Figs. 15 and 16 of Mr. de Muralt's paper, you will note that the trolley arms, which make this sweeping motion, are capable of adjustment. There is also an arrangement inside the cab permitting the movement by the operator of the three trolley arms simultaneously, and they are also each independently under tension, so that the upward pressure of the ordinary under-running trolley is practically reproduced by a side-sweeping or wiping motion of the trolley arms together with the lateral movement arranged for in the sections of trolley wires.

The arrangement used in the original plant on the Teltower road between Grosse Lichterfelde and Zehlendorf, which permitted of the flexibility in the contact arrangement between the trolleys and the trolley wires, and which also enabled the keeping of the three trolley wires the same distance apart, and keeping them under the same tension in cold and warm weather, consisted of heavy weights placed inside certain of the latticed poles, which weights, acting through a loose pulley and block with six pulleys, gave a strain of 1,500 kilos on the wire. These poles were about 40 metres apart, and they were somewhat heavier than the intermediate poles, and were set in a cement foundation.

The question which I desired to ask Mr. de Muralt was whether this arrangement, which seemed to me of considerable importance, was also employed on the Zossen road.

In connection with the concluding remark of President Steinmetz regarding the wear upon the trolley wires, and his statement that in foreign practice it was necessary to have the trolley conductors at almost a constant level throughout the entire length of the road, on account of the difficulty in securing adjustment with the foreign types of trolleys, where the trolley wire varies in height, as is frequently the case in American practice, I think that both of these matters are not as serious as one would be inclined to think.

One form of bow trolley which I have seen considerably used abroad, has a groove in which oil is placed, a slight amount of which is constantly keeping the surface between the trolley and the wire lubricated. In other cases the trolleys are so designed as to enable immediate replacement of wearing parts, the principal wear coming upon the trolley itself.

The various forms of trolleys permit of considerable up and down adjustment.

I had the pleasure of seeing the tests made on Messrs. Ganz & Co.'s road at the Alte-Ofen Island near Budapest in 1900, which led up to the installation which has recently been put in by this company on the Lecco-Colico-Sondrio-Chiavenna road in Italy.

In the installation at Alte-Ofen, the locomotive was equipped with a trolley which was raised and lowered by means of compressed air—the same device being used which operated the air-brake, and which also was used for forcing the solution in and out of the liquid rheostats. This ingenious arrangement saved the necessity of raising and lowering the rheostat plates. The single and double bow contacts are in use on the Swiss roads, and I saw them used upon one road in connection with the American type of trolley pole on certain equipments. There are certain advantages in the bow type of trolley in simplifying the difficulties of overhead construction, and there is not the same danger of the trolley jumping the wire, as is the case with the American type. The type of triple trolley which I have referred to, used on the three-phase road near Berlin, gave most excellent results. On the underground road in Budapest the trolley is adjusted so as to make a contact on the track rail, fastened to the low roof of the tunnel, and upon emerging from the tunnel to make contact with the higher overhead wire.

Mr. Townsend Wolcott:—I should like to ask one question: What is the average air gap in the polyphase induction motors as compared with the diameters of their armatures?

Mr. Frederick V. Henshaw:—The operation of great railroad systems by electricity instead of steam power is a subject that is very much before us and before the public at present, and the public is on the *qui vive* to see which railroad is going to make the first move. It is unquestionably a fact that express trains on steam railroads operating over long distances with few stops can be driven successfully by means of the induction motor, great distances and direct current at the present time being impracticable. The necessary acceleration can unquestionably be obtained by putting on enough motors; if necessary, you can put a motor on every axle. But it is worth remembering that the bulk of the traffic on every steam railroad system is in freight, and it would hardly seem reasonable to suppose that any railway company would go to the enormous expense of equipping a road with electricity for the sake of operating a very small proportion of its traffic, namely, the passenger traffic. If that is the case it would then seem that we come back to the question of individual motor torque. We might stand the three trolley wires, but we have to get the equivalent of high acceleration in the motor. In other words, it is utterly out of the question to put an electric motor on every freight or coal car. It has to be a locomotive, and instead of starting a light mass and accelerating it rapidly, we have to start a heavy mass and accelerate it slowly, or we must have the torque and the tractive power concentrated in a locomotive for freight service. It would appear to me, therefore, that until the torque or acceleration capacity of the alternating current motor is greatly increased, the prospects are not very good for the general equipment of large railway systems with such motors.

Mr. de Muralt:—I will try to answer the questions in the order in which they were put. First and last, the acceleration. I admit that this is a very important question, but I do not quite agree with Mr. Mailloux in saying that the alternating current motor is very much at a disadvantage in that respect. If in the Burgdorf-Thun railway we find only small accelerations, that is because no better are asked for by the officials of this road, but I believe that very much higher accelerations could easily be obtained with alternating current motors as well as with continuous current motors. It seems to me the question of acceleration is not really a question of the system; it is a question of putting enough power in motor-capacity in a car so as to get the required acceleration out of it. It does not really matter whether this power is in an alternating or in a continuous current motor.

Then in regard to the different points touched on by Mr. Stott, I do not know of any trouble that has arisen from poor contact made with that 10,000-volt line. I quite agree with him that if there should be any trouble it might be rather serious, and that a short-circuit might occur, but I think the pressure of the contact-making device with the wires can easily be so arranged, and particularly where the three wires are vertical, one above the other, as to cause no trouble whatever in this respect, especially as with 10,000 volts the current carried is of course very low.

As regards the distance between sub-stations, this of course depends to a great extent on the power required on the different parts of the road. In the particular case of the Burgdorf-Thun railway this power was rather large on account of the comparatively high grade. On a normal trunk line, 2½ per cent., I believe, is allowed rather a high grade, and this brings the sub-stations close together. In a case like the Manhattan Elevated or any road practically level, the sub-stations would be much further apart.

Regarding the lightning arrester on the sub-station, this is really one of the Siemens & Halske type, as the photograph shows, and I do not know that it has caused very much trouble. I have not investigated this question particularly, but I have seen lots of these lightning arresters installed, so I believe they must have given good service so far. I know though, that in a great many cases, lightning arresters of the Wurts type have also been installed, and as a matter of fact, even on the Burgdorf-Thun railway, some have been installed, probably to compare the two systems. None has been changed, so I think both must have given satisfaction.

As Mr. Hammer already remarked, the distance of the trolley wire from the ground is really not quite so important as President Steinmetz has pointed out, the bar contact device allowing also quite a variation in height. The contact device can be lowered so as barely to allow the wire to escape touching the car, and the contact will always be good.

The President also said that it would hardly suffice in a great many cases to have the car able to start on a 2½ per cent. grade. I quite agree with him, but the Burgdorf-Thun railway has no higher grade than this. Therefore, in this case it was not necessary. If the road had higher grades, I think provision ought to be made so that cars could start under any circumstances, but I do not see any difficulty in this. It is merely a question of putting on enough motor capacity.

I do not know exactly the average headway actually allowed in the time-table of the Burgdorf-Thun railway, but it is easily found that as the stations are dimensioned so as to allow two trains running at the same time, the line can allow as many trains at least as there are sub-stations. So I think that is just about the minimum headway that can be allowed.

The drop in voltage on the roads I have studied is, I think, usually limited to about 6 to 10 per cent. on an average, but in the calculations, I think a maximum drop of 15 to perhaps 17 per cent. has been allowed. This seems rather high to me, and is perhaps not exactly safe.

I have not heard of any appreciable unbalancing being caused by the rail being used as the third conductor, although the frequency used is somewhat high. I think lower frequencies are more advisable in general, as with high frequencies the skin effect might play quite an important part.

Mr. C. E. L. Brown has said, I believe, that he chose the higher frequencies chiefly because of those roads being supplied by central stations furnishing power for the motor cars as well as for lighting installations. He could, therefore, not very well go much below the figures chosen. For a railroad alone, I think he would probably have used a lower frequency.

The contact devices used on the Burgdorf-Thun railway last very well during summer weather and ordinary climatic conditions. When there is sleet on the wires, however, they are used up rather quickly. I have no data at hand as to the mileage they can stand, but I am told that they usually last the whole summer season without changing, while in winter they are actually sometimes changed during one trip. It also depends a little upon how the motorman handles his car. It is, however, very interesting to remark that they are easily replaced, consisting merely of a tube pressed into the two outer parts of the steel frame, and the material of this tube, even when it is badly cut, is not lost and can easily be made into another tube, so there is perhaps not as much lost in the use of these contact devices as in the case of ordinary trolley wheels. These contact bars are usually made softer than the trolley wire, and this is probably the reason why I have not heard of the trolley wire being much worn. As a matter of fact, I have inquired into breakdowns on the Burgdorf-Thun railway and I was told they had been remarkably few, I think only two or three in the whole time.

The air-gap of the motors used is, if I am correctly informed, between 1½ and 2 millimetres, which I think is just about what is standard for a normal stationary induction motor.

A MEMBER:—I would like to hear a word from the writer of the paper on the flatness of the top of the speed curve of which our President spoke. What I refer to is the duplication of the old cable experience—not being able to make time.

MR. DE MURALT:—I am very glad you have touched on that point, because it gives me a chance to correct a current impression that only the alternating current system is at a disadvantage in that respect. Personally, I am not of that opinion, for the following reasons: If you want to make up time, what has been the cause? You have lost time either on account of the overloaded motor not having been able to run up to schedule time or else on account of the stops having been too long, because you have had too many passengers to handle. In both cases I do not think that the continuous current motor can make up time, because in both cases the load on the motor will be more than average, that is to say the speed will be really lower than average. Now the alternating current motor will under the same conditions also not be able to make up time, but in comparison with the continuous current motor, it will surely prevent losing more time. So I consider this question really an important one by showing an advantage rather for the alternating current motor than the continuous current motor.

MR. MAILLOUX:—I am very much surprised to hear Mr. de Muralt seriously express the opinion that there should not be any difference between the two forms of motors in the acceleration attainable. If that be true, then it must be possible to make induction motors that are capable of developing several times their running torque. Now I understand that while this may be theoretically possible, it is not industrially feasible. If we investigate the mathematical theory of acceleration, we readily see that the rate of acceleration possible depends exactly upon the amount of tractive effort or pull which the motor can exert over and above that which is necessary to overcome train resistance, grade resistance and all forces opposing the motion of the car; in other words, the difference between the total pull and the pull actually operative in overcoming train resistance of all kinds or what is called the net pull at that particular speed, represents the pull which forms the component of energy going into acceleration. Now, if we cannot obtain that net pull, I do not see how it is possible to get the acceleration. If we, for instance, can get a pull per ton, we will say, of 200 pounds, when 10 pounds is needed for overcoming train resistance, we will have 190 pounds of pull per ton available as the component of energy that goes into acceleration or as the force factor of the kinetic energy stored in the car. The rate of acceleration would be approximately 2.1 m.p.h. per second. If we can develop only 30 pounds, it is evident we have only 20 pounds available for acceleration, which would mean less than 0.25 m.p.h. per second. Let us suppose the running torque is more than that, because the train at full speed would have a higher train resistance. Let us suppose it is 30 pounds. In that case with our induction motor capable of developing, we will say, 100 pounds per ton, we would have available 70 pounds per ton (or about 0.8 m.p.h. per second, whereas in the other case we would have 170 pounds (or about 1.9 m.p.h. per second.) That represents the difference between the two forms which is available for acceleration and which produces acceleration. I have investigated the matter very thoroughly, because I have had to deal with problems where I very seriously contemplated the use of alternating current motors, but I have found it impossible to expect of an inducton motor any acceleration exceeding 1¼ to 1½ miles per hour per second. I would be very glad indeed to know that it is possible to obtain it. On the other hand I know that with direct current motors there is no difficulty in going as high as 2½. I feel satisfied that the cases that I know of where I have seen alternating current motors used are all cases in which the acceleration is manifestly slow; so much so, as I have stated previously, as to be noticeable to American engineers accustomed to much higher accelerations. I would like very much to know of cases where a rate of acceleration exceeding 1½ miles per hour per second has been obtained with an induction motor. While it is theoretically possible to put on enough motor capacity, yet we all know that the limit is reached when we have so many horse power per ton of total weight. In other words, one might reach a point where the weight of motor necessary to produce the required acceleration was such that the train would only propel itself without any useful weight. Of course those are not industrial conditions, they are not commercial conditions, and yet they are precisely the conditions which have militated against the use of the induction motor in this country, as the President has very well pointed out. The conditions in this country are somewhat different. We have not so many cases where the distances are long and the stops few. On the contrary, the conditions all point to high speed, frequent stops, and conditions of a kind which absolutely preclude the use of the alternating current motor; and while I do not disbelieve in its possibilities, yet I certainly think that at the present time the field where it can be successfully used is extremely restricted. I am satisfied that it is not so much a question of the people waiting to see which railroad is going to use it first, as it is a question of the railroads waiting to see which other road is going to be fool enough to try it first. That is my opinion—in the present state of the art; I do not wish to state that things will always remain so, but I believe, as the President has very well pointed out, that in the present state of the art, and in ninety cases out of a hundred in this country, the direct current system is, on the whole, that which would meet most, if not all, the requirements; and if one is restricted to one system, and cannot have that which combines the advantages of two, the engineer will be almost sure to select the direct current system. In fact, he has no choice.

MR. DE MURALT:—I can perhaps agree with Mr. Mailloux that where extremely high accelerations are asked for, the alternating current motor is, in the present state of the art, not quite as well suited as the continuous current motor. I would like to state, however, that accelerations of 1½ miles per hour per second have really been reached, within my knowledge, and I think even something above. I do not know anything of 2½. I do not think that has been reached, but I do think that it is really only a question of proportion between the running torque and the torque during acceleration. I do not exactly see why it should not be possible to design a motor powerful enough to give the acceleration wanted, as long as it does not exceed certain extreme limits, and I think this can be done as well with the alternating current motor as with the continuous current motor.

MR. MAILLOUX:—I would state that I think it can be done with some means of variable speed ratio, that is, some means in which the motor can be run up to full speed, and the car connected by means of some clutch device allowing the velocity ratio to be changed from a very high value to the lowest value required for the particular maximum car speed required. I very seriously doubt, however, if it will ever be done by the induction motor with any such methods of design, operation and control as have been under discussion this evening. In fact, I believe it is physically impossible to obtain an acceleration of 2 or 2½ miles per hour per second with such methods.

PRESIDENT STEINMETZ:..I do not agree that it is necessarily impossible to get accelerations of 2½, 3 or even more miles per hour per second from an induction motor. It can be done, but it is questionable whether it is commercially practicable. All this depends on the point of view. Now, I exclude first the case, occasionally met, where the conditions are so severe that the weight of the motor is a large percentage of the train weight; so that doubling the motor capacity of the train almost doubles the train weight and increases the dead weight so that twice the motor torque does not give you anything like twice the acceleration, and so an absolute limit of available acceleration is reached. But if we exclude these very severe conditions, it is true that by increasing the motor capacity we can get a very rapid acceleration. However, it depends on what consideration you base the motor capacity. As a rule, in designing a railway motor, capacity is based on the average load; that is, if we put say four 50-h.p. motors on a car, it means that the average load required of the motors will be such that four 50-h.p. motors will carry the car over the track. In other words, the amount of motors installed corresponds to the average load of the car, and the maximum acceleration which you can get corresponds to the maximum torque these motors can give. Now in the series motor, if you assume under average running condition, say 3 per cent. loss in the resistance of the motor, that means the maximum acceleration you can get is at least 33 times the average running torque, which is practically infinity, or beyond the slipping point of the wheels. That is with the continuous current motor you can get any acceleration, up to the slipping point of the wheels. If you take the three-phase induction motor, and assume that the design of the motor capacity of the car corresponds to average running conditions, then the maximum torque of such motors will probably be three to four times the average torque and there you stop. To get twice this acceleration, you have to put in twice the motor capacity required for the average condition of running. Even if the train weight is not seriously increased, this merely means that the motors are underloaded, under average running conditions, the effect of which you know on the power factor and the efficiency. If I am not mistaken, induction motor propositions have been made where the concatenation of two motors in starting was used, and in running half the motors cut out, that is the locomotive was supplied with twice as much motor capacity as was necessary for running, merely to get the starting acceleration. This is not a very economical arrangement.

MR. MAILLOUX:—I only wish to add one word as a sort of clincher. It is this, the engineer who investigates this question has to consider one more question which perhaps is not included by the designer of motors or the manufacturer. That is the question of interest on the investment. When I said that these things are not practicable, I meant from the standpoint of one who makes an investment with a view of getting a financially satisfactory return on it. If we have a car so loaded that it cannot carry any useful freight, then it is evident that the cost per ton or the cost per passenger carried would have to be increased enormously to make that road pay, and the case is worse still if the cost of the equipment per ton carried be greatly increased at the same time. If all these things are considered, it will be found that the limitations are reached with the alternating current motor before attaining an acceleration such as was spoken of. That is what I meant.

MR. DE MURALT:—I am afraid that bringing in the question of investment and return on investment is putting the discussion on too general a basis, which, as I started to say, is not very good for discussion. I think we could easily find an extreme case to prove that a special road would be better off with alternating current, and we could also find another extreme case to prove that another special road would be better off with continuous current.

MR. MAILLOUX:—I did not mention a special case, except the special case of high acceleration. That is the only condition I stated, and I said that for those cases the alternating current motor was not suited. That at once states the condition; it limits it to a particular case.

PRESIDENT STEINMETZ:—If there are no further remarks, I call upon Mr. de Muralt to close the discussion.

MR. DE MURALT:—I think it is rather difficult for me to close this discussion, but I am glad to say that my paper brought out quite a number of points which I hope may have been interesting to you.

MR. MAILLOUX:—I would like to move a special vote of thanks to Mr. de Muralt for his paper. I think it is very gratifying to us here at this Annual Meeting to have one of our foreign members read a paper which is as interesting as Mr. de Muralt's paper has proved to be. While it may not be exactly according to our usual custom, I think we may make an exception in this case and extend a vote of thanks to our distinguished foreign member and guest. [The motion was seconded and carried.]

PRESIDENT STEINMETZ:—Mr. de Muralt, I do not quite acknowledge you a foreign member, because I know you have been living in this country for quite a number of years and also by other ties are very closely attached to the United States. In the name of the INSTITUTE I thank you very much for your very interesting paper.

THE SECRETARY:—There are 149 proxies represented to-night, and with the attendance in person this is more than the quorum required for a legal meeting by the Constitution, which is 10 per cent. of the membership.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 28, 1902.

The 166th meeting was held this date at the house of the American Society of Civil Engineers, 220 West 57th street, and was called to order by President Steinmetz, at 8.15 P. M.

PRESIDENT STEINMETZ:—Gentlemen: While calling to order the 166th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, I extend a hearty welcome to our guests—the officers of the United States Army and Navy, who honor us not only by their presence, but still more by participating in the work of the evening, to the members of the Society of Marine Engineers and Naval Architects, the members of the American Society of Civil Engineers, the members of the American Institute of Mining Engineers, and the members of the American Society of Mechanical Engineers.

I am happy to be able to state that the INSTITUTE has been presented with a very good portrait of Lord Kelvin who, as you know, was recently our guest. This portrait has been presented by our Committee on Papers, and is now on exhibition in this hall, and will be permanently placed in our rooms.

We will now proceed to the presentation of the papers of the evening. I am happy to say that we have a considerable number of interesting papers,and also expect a very interesting discussion. Therefore, it becomes necessary to abstract the papers, and ten minutes will be given to each paper for that purpose, and then each gentleman who wishes to take part in the discussion will be allotted five minutes. The author of the first paper, Mr. Caryl D. Haskins, is at the present time on the Atlantic, and so cannot be here, and therefore an abstract of his paper will be presented by our Secretary.

The following papers were then read:

"Civilian Coöperation in the development of Electrical Devices for Military Purposes," by Caryl D. Haskins; "Electricity in its Application to Sub-Marine Mines," by Capt. John Stephen Sewell, U. S. A.; "Wireless Telegraphy—United States Navy," by Lieut. A. M. Beecher, U. S. N.; "Electricity in the Navy," by Lieut. Harry George, U. S. N.; "The Military Cable System of the Philippines," by Capt. Edgar Russel, Signal Corps, U. S. "The Reasons for the Change of the Navy Standard Voltage from 80 to 125," by Lieut. W. V. N. Powelson, U. S. N.; "Electricity in Permanent Seacoast Defenses," by Maj. George W. Goethals, U. S. A.; "Submarine Cable Testing in the Signal Corps, U. S. A.," by Townsend Wolcott; "Electricity in the Navy," by Walter M. McFarland; "Electricity in the Signal Corps," by Col. Samuel Reber, U. S. A.; "Emergency Engineering for Harbor Defence," by Dr. Louis Bell.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

CIVILIAN CO-OPERATION IN THE DEVELOPMENT OF ELECTRICAL DEVICES FOR MILITARY PURPOSES.

BY CARYL D. HASKINS.

It has been said that universal peace may be expected when the engines of war become so sure and deadly that no man dare fight. This statement is somewhat crude and doubtless does a grave injustice to the standard of human courage, although perhaps it holds a germ of truth. It is certainly true that the increased deadliness of modern war-engines has been followed by a marked diminution of fatalities in action, and such sanguinary engagements as have occurred in recent years have generally been under conditions involving obsolete equipment.

There are few directions in which electricity is capable of a greater variety of useful applications than in connection with the art of war, and the sole purpose of this brief paper is to make an appeal for closer coöperation between civilian electrical engineers and that other large group of scientists and engineers; namely, officers of the United States Army and Navy.

The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has attained a standing and position which entitle it to respect as a national institution; and it seems right and proper that this INSTITUTE should serve, so far as it may, the interests of the United States Government in connection with the improvement and development of our war equipment and methods.

To the officers of the United States Army and Navy, electricity is but one of many forces to be utilized in connection with military appliances and systems. It is therefore not presumptuous to assume that we, who are specialists in this science alone, may well hope to be of material and lasting assistance in the development or betterment of appliances of this class.

It may perhaps be said that such conditions of coöperation already exist, and it is quite true that in many directions this is the case. Close analysis of the facts, however, will show that such coöperation has been almost wholly confined to those military applications of electricity which are closely paralleled by similar applications in industrial pursuits. There are certain classes of applications, however, which are so purely military in their character as to have received no necessary attention by reason of commercial demands.

I may cite, for example, the general question of range and position finders, or, to make the proposition yet more concrete, the more or less automatic transmission of angles from remote points in a way so positive and reliable as to withstand the rough and arduous conditions of sustained military service. I may also cite the development of the submarine mining system and its control. In connection with this work as well as with range finding systems, etc., I have had some actual experience under service conditions.

Mining systems are probably typical of those military applications of electricity which have been developed exclusively within the service. None of the privileged few who are familiar with the United States system as compared with foreign systems of the same character can fail to appreciate the high genius of Gen. Abbott and his coadjutors, yet I feel that intelligent study by a body of engineers, whose specialty and sole occupation is the study of applied electricity, might result in materially improving the effectiveness of the system and its devices.

I fully realize that the mine defence system of the United States, in common with those of most European countries, has been regarded as necessarily an official secret of a certain limited branch of the service, formerly the Corps of Engineers, now the Artillery Corps. It is, however, well known that such secrecy cannot be very effectively maintained, as is well proved by the fact that there are probably few officers in our service who are not familiar with the systems in use in most of the large European States, and it is probably true that Gen. Abbott's system (now greatly modified) has been well understood in foreign services for some time. Proper official secrecy does not, in short, bar the mining system from such benefits as might result from civilian collaboration.

The rapid and accurate transmission of angles in connection with base line range and position finding from permanently established stations, and the indication of these angles (or even their resultants) at gun positions, mine control stations, or in mortar batteries, present an especial field in connection with which civilian engineers of wide experience might be of material aid, since in this field very numerous alternative methods may be resorted to, each quite different from the other, and each involving the application of ideas based on devices which have been used either in the laboratory, or commercially for other purposes. Such devices might be modified to form the bases of successful systems. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS might very properly take up the study of such abstract problems as these, which together with many similar propositions are so academic in their character as to be quite free from the least suspicion of commercialism.

There is another field in which civilian engineers might be of material service to the regular establishment. I refer to the elaboration of plans and the locating of materials for emergency projects. It is quite certain that the civilian engineer is best situated to keep track of materials manufactured for commercial use and to advise application for war purposes. When it becomes necessary to accomplish military ends with makeshift materials, the aid of the civilian engineer in advising with what materials the end can be accomplished, and where these materials can be located, is obviously likely to be helpful. It would seem unwise to wait until the emergency arises to give consideration to this important subject.

It is to be remembered that a war with a first-class power would necessitate the immediate execution of a large mass of electrical work, especially in connection with coastwise defences, communications and mining. A very large number of trained men must necessarily be employed in order to execute such work promptly, and these men must be drawn either from the enlisted forces of the army, or must be raised as volunteer troops after the emergency has arisen. Some comprehensive plan should be elaborated for the finding, organizing and concentrating of a volunteer force of trained electricians officered in part by electrical engineers, and commanded by officers from tha branch of the regular establishment responsible for the work under execution.

A systematic study of this problem would almost certainly result in recommendations for the establishment of a permanent reserve force, possibly taking the form of a national militia and comparable with the Royal Volunteer Electrical Engineers of Great Britain. It is even conceivable that such an organization might very properly be found to require a permanent cadre, forming a small skeleton attached to the regular establishment, or more probably a small permanent staff of officers.

The volunteer establishment of Great Britain includes 20 companies of submarine miners, which are organized into "Mining Sections," so-called, each section comprising 13 officers and 183 men; and the "Volunteer Electrical Engineers" are organized as a battalion, having 29 officers and 547 men.

I do not wish to be misunderstood as ecommending or advocating the organization of any specific force. My sole purpose is to recommend the whole great question as one worthy of attention at the hands of the officers of the regular establishment and of the members of this INSTITUTE.

There are some dozens of military electrical problems which must go on through a long course of elaboration and development in common with all other war methods and appliances, and I therefore respectfully suggest to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS that it might be highly proper to constitute a committee whose sole purpose should be to coöperate with the various bureaus of the army and navy in connection with the development and betterment of electrical war projects. It is reasonable to anticipate that such a committee would be heartily welcomed by, and highly useful to, the sister services and the Government.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

ELECTRICITY IN ITS APPLICATION TO SUBMARINE MINES

BY CAPT. JOHN STEPHEN SEWELL, U. S. A

A system of submarine mines usually involves stationary torpedoes planted under water, anchors for holding them in position, cables for connecting them electrically with the shore, and operating apparatus in a sheltered position on shore. The torpedo itself is usually a metal case, containing a charge of suitable explosive, with necessary detonators, etc. It may, and in shallow water usually does, rest on the bottom, the metal envelope being in this case sufficiently heavy to act as an anchor. In water more than 35 or 40 feet deep, the torpedo is usually buoyant, and is held in place by a separate anchor and mooring rope. Torpedoes may be purely mechanical in their action; in this case, there are usually a number of movable pistons projecting through stuffing boxes at various points, and so arranged that if driven in by the impact of a vessel, they will explode a detonator, which, in turn will explode the torpedo. It will be readily granted that such torpedoes are dangerous to handle, and are not likely to remain long in an efficient condition in sea water. Again, in some rare instances, use may be made of what might be called self-acting electrical torpedoes, in which a battery and circuit-closer, in series with an electrical detonator, are enclosed in the metal case, along with the charge of explosive. The circuit-closer is supposed to act under the impact of a vessel, and the battery does the rest. Some form of dry cell is manifestly the only proper battery for such uses.

In planting self-acting mines, it is necessary to have a safety device which will maintain an open circuit, in spite of the circuit-closer, until the operations of handling and planting are completed, and those engaged in the work have had time to put a safe distance between themselves and the mine. After this, such a torpedo is dangerous alike to friend and foe, and its removal is an exceedingly delicate operation. For this reason. and also because a thoroughly satisfactory safety device is very hard to find, self-acting mines have a very restricted sphere of usefulness.

By far the greater part of all submarine mines are electrically operated from the shore. This follows directly from a consideration of the conditions to be met in devising a system of mines. It is very desirable for a mine to explode automatically when struck by a hostile vessel; but it is equally desirable for it not to explode if it is struck by a friendly vessel; the defense should also be able to explode the mines at will from the shore, in case a hostile vessel comes near, but seems likely to miss them. All these things are rendered possible by mines electrically operated from the shore.

It is necessary, of course, to proceed with accuracy and precision, in order to attain successful results with such a system. Mines are, primarily, obstructions and not weapons; their principal function is to prevent the enemy from running by the batteries, which experience has demonstrated that he can do, if he has a clear channel. They must be located where, if he tries to remove them, he will be detained under the close fire of the shore guns; otherwise he would remove them and then run by. They must be sufficiently numerous to prevent his opening a channel through them by the sacrifice of any reasonable number of vessels, sent in to receive an explosion and then turn to one side and sink out of the channel. They must be accurately located and planted in regular order, so that there will be no mistake about exploding the proper mine in judgment firing and so that in case of automatic firing, the exploded torpedo may be replaced with the least delay.

It is customary to plant mines in smaller and larger groups; (usually more than one torpedo is attached to a single cable core) and the various cores, as they approach the shore, are gathered into a multiple cable of several cores. Thus, starting with a cable of ten cores, it should be laid by the most direct line from the operating casemate to a convenient point in the rear of the line of mines it is to serve; there, by means of a large junction-box, it would be connected with ten single-core cables, each leading to one of a line of smaller junction-boxes; at the small junction-boxes, each single conductor branches into perhaps three other single conductor cables, each of the latter going to a torpedo. By this arrangement, when firing is by judgment, which involves some uncertainty as to the actual distance of the hostile vessel from the mines, the defense explodes three charges at once, thus increasing the probability of an effective blow; if, on the other hand, the hostile vessel strikes a torpedo, only that one will explode, and being in contact with its target, it ought to be sufficient.

Coming now to the electrical arrangements, if firing were by judgment alone, nothing would be needed but a circuit from the firing battery through the detonators in the torpedo to earth, with a firing key in the casemate. Even very defective insulation would not interfere with the working of the system, if the firing battery was enduring and sufficiently powerful. It would interfere with the daily tests, however, because of the variations in resistance which would occur even if no leaks or other defects developed in the torpedo itself. If firing is by contact alone, the necessary arrangements are a little more complex.

In order to admit of daily electrical tests—which must include the circuit through the detonators to be of any value—there must be a continuous circuit through the torpedo; it must be of high resistance, so that even if the firing battery is on, it can not fire the mine. There must be a circuit-closer in series with the detonators, and in parallel with the high resistance. When the mine is struck, the circuit-closer acts, and opens up a circuit of lower resistance through the detonators. It is assumed that the detonators are of the type having a continuous bridge of fine wire, surrounded by some fulminating substance, and designed for a relatively large current under moderate e. m. f. This is the most certain and reliable form, and is always easy to obtain. If the firing battery is on, the torpedo should explode when the circuit-closer acts.

It is desirable, however, to know whether a torpedo is struck, or whether its circuit-closer acts from any other cause, even if the mine is not to be fired. Moreover, it is objectionable to keep the cables under such high voltage as is necessary in a firing battery. It therefore becomes desirable to have another battery of very constant e. m. f. always on the circuit. Its e. m. f. and all the resistances in circuit should be so proportioned that normally a tiny current is always flowing; but when a circuit closer acts, this current should increase to such a point that it will drop a signal, showing to which triple group the torpedo belongs, and also close the circuit of the firing battery through the corresponding cable core. In case the torpedo is fired, the explosion may cause the circuit-closers of neighboring mines to act, and thus the whole system might go up, seriatim. To prevent this, some device is needed which will allow the firing current to flow long enough to explode certainly the mine that is struck, but which will break it immediately thereafter, and keep it broken long enough for neighboring mines to right themselves. It should be remarked here that if ground mines are used for automatic firing, the circuit-closer must be carried in a buoy, similar in form to a buoyant torpedo, anchored to the ground mine, and having an electrical connection with it; so that, with ground mines, the requirements are the same as with buoyant mines.

It will readily be seen that to accomplish all the above objects a more or less complicated set of apparatus is required. It is a good plan so to arrange the signal drops that when they fall they will close a bell circuit, thus causing a bell to ring continuously until the signal is raised; it is also well for the device which cuts off the firing battery after an explosion to ring a bell as long as the firing circuit is open; this gives reasonable assurance that a mine has exploded, even if in the noise of a battle the explosion itself is not heard; pilot lights would do as well as a bell. It is also well to have a very feeble battery for testing purposes only; thus it will be already seen that there may be as many as five separate circuits to provide for in the operating casemate. In addition there may be one more; if a torpedo is struck and fired, the end of the cable leading to it will form an earth which, if not cut out, might be sufficiently good to keep throwing the firing battery on; it would so alter the resistances as to interfere seriously with the proper working of the system, at any rate. At the triple junction-box, a fuse could be inserted, able to carry the firing current, but susceptible of being blown by a more powerful one to be applied as soon as the other mines of the group have righted themselves. If now we assume that a small engine and dynamo are used in connection with storage batteries to supply current to the various circuits, it will readily be seen that the switchboard problem in the casemate is not a simple one.

If, in addition to automatic firing, it is desired to use judgment firing, we must be able to switch out the high resistance in the mine, or else have this resistance in the form ot the primary of an induction coil, with additional detonators in its secondary circuit; in this case, an intermittent or alternating current of high potential and small volume flowing in the primary would induce a firing current in the secondary. A whole triple group would then be fired, and the corresponding core of the multiple cable would be detached from the operating apparatus altogether, until such time as the mines could be replaced.

In purely automatic firing, the high resistance might be omitted altogether, but then a break in the cable core would give the same indication as a mine in normal condition; and the torpedo itself might be filled with water and sunk to the bottom without the fact being discovered.

The daily tests consist in measuring the resistances of the various circuits, and testing all movable parts in the operating casemate. Damage to the system always affects these tests and the expert electrician in charge must learn to infer from his tests what is the probable nature of the damage.

It will readily be seen that except for purely judgment firing, the insulation resistance of cables and joints must be very high, and must remain so. Details of apparatus actually in use have been omitted in this paper, because they are classed as confidential; but enough has been said to show to an electrical engineer that submarine mining presents some problems that demand serious attention. Not the least of these is the problem of junction-boxes which will allow of rapid jointing work of a quality sufficiently good to withstand submersion in sea water for months at a time. Another serious problem is the cable itself. It takes time to make it. If it is kept in store, either wet or dry, the insulation becomes brittle and when the cable is unwound from the reels, in laying, the insulation cracks. Hitherto, the cable used for this purpose has been insulated, taped, and armored. While the work has been of a high grade, it seems to the writer that we will have to come to the use of cable having a lead covering outside of the insulation and steel wire armor outside of the lead. Then, as long as the lead is intact, cracks in the insulation will be of no consequence. But this form of cable again, will be heavier, harder to handle. more difficult to splice, and considerably more expensive than the armored cable without the lead.

Even after the details of a system of mines are satisfactorily worked out, the planting is a very serious matter, and always will be, unless we discover some way of controlling and firing the mines by induction, without electrical connections from the shore, thus eliminating the cable. Possibly the development of wireless telegraphy may ultimately make this possible, but it is not yet in sight.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

WIRELESS TELEGRAPHY—UNITED STATES NAVY.

BY LIEUT. A. M. BEECHER, U. S. N.

The navy is on the eve of adopting a new system of signaling, commonly known as wireless telegraphy. We are all so familiar with the ordinary use of telegraphy between stations connected by conducting wires or cables, that the idea of doing away with these seems very strange at first. However, we have long known how to transmit signals from one point to another in a conventional language without a connecting wire between them. Thus visual signals, by means of flags, semaphores, or heliographs, by day, and by searchlights, lanterns, or rockets, by night, have long been used. Sound signals using either steam whistle or gunfire are not uncommon during either daylight or darkness, especially in thick or foggy weather. The only difference is that while with visual signals, light waves or vibrations are utilized, and in sound signals, sound vibrations, in wireless telegraphy, electric vibrations are put into requisition. In order to understand the mode of generation, propagation and reception of electric, or Hertzian waves, we can reason by analogy, and to that end it may be well to recall some well-known facts. A sound is the effect on the ear of a certain vibratory movement in the air, and we can distinguish sounds of different pitch according to their rate of vibration. When a sound is produced at any point it is transmitted to the whole elastic medium surrounding it, and is stopped or deadened only by soft bodies. Sound vibrations may be detected by the ear or by placing in the path of the waves a body whose period of vibration is exactly the same as that of the source; thus a fiddle string will be caused to vibrate by sound waves given out by any instrument tuned to the same pitch, or a singer with a powerful voice, by singing loudly near a wine glass a note corresponding to its vibrating note, will cause the glass to vibrate and this vibration may be so violent as to shiver the glass.

Light, like sound, is propagated by waves. The difference is that the medium (ether) which vibrates is not the same. The periods of vibration are considerably shorter and the velocity of propagation enormously greater. Electric waves are also propagated in the ether and are very closely associated with light waves. Hertz made a masterly study of these electric waves and by his remarkable experiments has shown that they are propagated through all non-conducting media and have most of the properties of light. They are reflected on conducting surfaces, are refracted in insulating bodies, and can be polarized. They travel at the same velocity as light, about 186,000 miles per second. It is seen, therefore, that there is a very close analogy between electric and light waves.

There are, however, certain properties of electric waves which are very different from those of light Thus it is found that they are propagated not alone in straight lines, but that they follow along the surface of conductors. They should not, however, be confounded with the other form of electric waves with which we are more familiar. I refer to electric currents. This property of these waves, by which they follow along the surface of a conductor, explains many facts which have been noted in connection with wireless telegraphy. Thus it has been found that communication over salt water is much easier than over fresh water, and that signals may be sent over certain sections of land more easily than over others, or even than over fresh water. It is particularly difficult to get good wireless communication over sandy ground. In each case the ease of communication depends upon the conductivity of the intervening surface stratum, whether it be land or water. This peculiarity of Hertzian waves also accounts for the fact that the curvature of the earth does not interfere with their propagation, so long as the intervening surface stratum forms a conducting medium. These considerations tend to limit the field of wireless telegraphy to the ocean, and it is particularly fortunate that this happens also to be the place where wire communication is most difficult, or even impossible, in such cases as between ships.

Before proceeding to a brief description of the apparatus employed in wireless telegraphy, it should be pointed out how these Hertzian or electric waves are produced, as they are apparently so different from the other variety of electric vibrations, the so-called electric currents with which we are familiar in conducting bodies. An electric current effects a comparatively slow equalization of potential between different portions of a continuous conducting circuit. On the other hand Hertzian waves are generated by an electric spark or an electric discharge and are propagated through space without the aid of a closed circuit. It was shown by Prof. Oliver Lodge in 1876, and again by Dr. Hertz in 1888, that such an electric discharge was not, as was long believed, a mere instantaneous leveling up of the difference of potential between the two electrified bodies, but rather that it took the form of a series of surging waves, inconceivably rapid, oscillating until balance was restored. Moreover, it was shown that these surging waves were capable of setting up similar waves in conducting bodies in their vicinity, provided these bodies were of such electrical capacity as to be able to vibrate electrically at the same rate as the body which emitted them. Such, then, are the waves with which we must deal in wireless telegraphy. From the fact that sparks are always necessary at the sending station, this form of signaling is sometimes called spark telegraphy. Hertz, who did more than any other man to elucidate the properties of these waves, cannot be considered the inventor of wireless telegraphy. Indeed it is difficult to ascribe the discovery to any one man, as, in its present form, so many inventors have contributed to the final result. The sending apparatus is very similar in most of the systems so far produced. It consists essentially of an ordinary Ruhmkorff coil for generating sparks. Specially designed apparatus is generally used for making and breaking the primary circuit. A battery of cells is sometimes used in connection with accumulators or storage batteries for supplying power, but when available and where greater distances of transmission are desirable, a dynamo, either with or without accumulators, is commonly employed to excite the primary of the coil. In its simplest form the battery or dynamo is placed in the circuit with the primary winding, in which also the sending key (ordinary make and break) is inserted. One pole of the secondary winding is then grounded, while the other is electrically connected to the aerial wire. These connections are shown in Fig. 1. These simple connections at the sending station are not now commonly used, but are somewhat complicated by employing an ordinary transformer and a condenser, a battery of Leyden jars, in addition to the apparatus first used. These are used in order to syntonize the apparatus. Fig. 2 shows one arrangement of connections when using the transformer and condenser.

Different arrangements have been adopted by inventors for

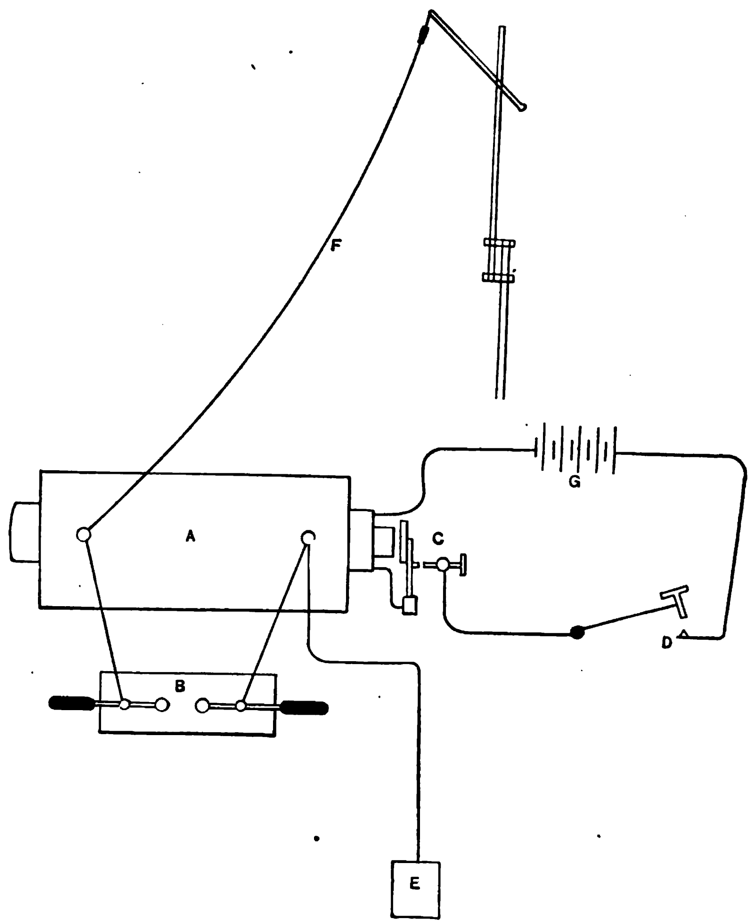


FIG. 1.—Sketch of Sending Connections. (Non-syntonic.)

A.—Induction Coil. B.—Spark Gap. C.—Circuit Breaker. D.—Sending Key. E.—Earth. F.—Aerial Wire. G.—Battery or Dynamo.

varying the inductance and capacity, but no attempt will be made in this short paper to indicate these. The difficulty in obtaining thoroughly satisfactory results in so-called syntonized apparatus will be pointed out later when considering the receiving apparatus.

Various forms and arrangements have been used for the aerial. In most cases on board ship a single wire is used, carried by a sprit or gaff from the masthead. This wire, sometimes naked and sometimes with insulating covering, must be very carefully insulated with hard-rubber or other efficient insulators at the masthead and at all other points where it might come in contact with metal portions of the ship. In some cases two or more wires are used, separated from each other by insulating spreaders, but joined electrically to a single wire at the bottom before reaching the instruments. Wires arranged cylindrically have likewise been tried and metal cylinders have replaced the wires in certain cases. These various arrangements all serve the same purpose, of radiating the electric or Hertzian waves when sending, or of receiving them when the proper connections are made with the receiving apparatus. It should be noted that a station cannot send and receive at the same time. There is greater divergence in the apparatus employed by different inventors for receiving than for sending wireless telegraphic signals. Still nearly all are following the same general lines.

Receiving apparatus may be classed under two general heads. First—those in which a coherer is used with a relay and Morse recording apparatus, and Second—those in which a loose contact or microphone is employed with a telephone receiver. In the latter case no relay is employed and there is no recording apparatus, the message being received by telephone as a series of short or long buzzes, corresponding to the dots and dashes of the Morse code. We will discuss briefly each of these different kinds of receivers, and, as the coherer in the one and the loose contact or microphone in the other are the essential features of each, they will be briefly considered.

The coherer was invented by Prof. Branly in 1890, and without it none of the present wireless telegraphic apparatus using a Morse recorder could have been made. It consists of two cylindrical metal plugs, usually made of silver, placed in a glass tube, with a certain short space between them partially filled with metal filings. Branly made the remarkable discovery that these metal filings ordinarily offer a high resistance to the passage of an electric current, but that under the influence of an electric spark, the resistance is enormously reduced, and the coherer then becomes a conductor and remains so for a considerable time, or until mechanically de-cohered by being shaken or lightly tapped. The spark seems to cause the filings to arrange themselves end on, forming metallic chains between the electrodes.

This effect of a spark is felt at a great distance, indeed it is impossible to tell the maximum distance at which it will be effective, but it is safe to say that its influence will reach to a distance of 100 or 200 miles in well-constructed apparatus. A coherer enclosed in a metal box is not influenced by a spark, even if produced nearby. If, however, wires connecting up with the electrodes are led out of the enclosing box, the coherer is again affected. This principle of screening the coherer is employed to keep it from being influenced by the sparks produced by the transmitting apparatus at the same station. The coherer is placed in a local circuit with a relay and single cell of low voltage. Under normal conditions the very high resistance of the coherer prevents current from passing, but under the influence of an electric spark, the resistance is broken down and the pass-

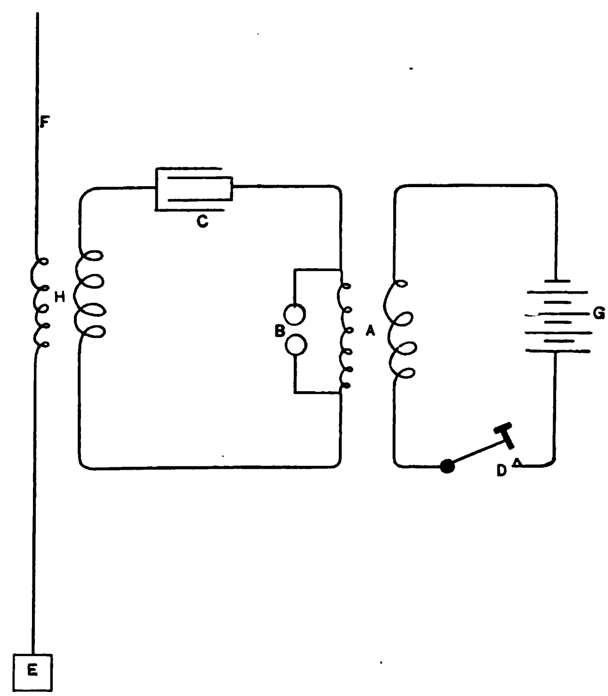


FIG. 2.—Arrangement of Sending Connections. (Syntonic.)
A.—Induction Coil. B.—Spark Gap. C.—Condenser. D.—Sending Key. E.—Earth. F.—Aerial Wire. G.—Battery or Dynamo. H.—Transformer.

ing current actuates the relay. In the derived circuit is an ordinary Morse recording apparatus, and also an ordinary electric hammer which is arranged to tap the coherer gently and thus restore its high resistance by mechanically shaking up the filings between the electrodes. It was pointed out that an electric spark was not a single discharge, but rather a series of inconceivably rapid oscillations backward and forward between the terminal points until balance was restored. The periodicity and length of the waves thus sent out depend upon the capacity and inductance of the conductors discharged. By varying these it has been sought to make certain transmitters affect only certain receivers, or in other words, to syntonize the transmitting and receiving apparatus so as to make selective signaling possible. This has in practice been successful to only a very limited extent. In fact, it may be said that about the only result so far accomplished has been to increase the range of signaling; receivers whether in or out of tune being affected at shorter ranges. The difficulty seems to be due to the very high resistance of the receiving circuit. It takes so much energy to break down the resistance in a coherer, that the oscillations are damped or deadened after one beat. We may liken it to a pendulum swinging in molasses, the resistance of which will practically bring it to rest after a single swing. If this reasoning is correct, we may not expect thoroughly satisfactory results in so-called syntonized apparatus using a coherer receiver.

We will now briefly consider the other form of receiving apparatus using a loose contact in place of a coherer and a telephone in place of the relay and Morse recorder. There is a marked difference between these two methods of receiving. A coherer being influenced only by electric potential must be placed at a potential loop, preferably at the top of the aerial receiving wire, while the microphone, or loose contact, should be placed near the earthing point of the aerial wire where there would be a loop or maximum of current oscillations. It is difficult to understand this difference, unless we remember that in the latter case using a loose contact, we also employ a telephone which is an extremely delicate instrument for detecting variations in current strength. A coherer might be used in place of a loose contact with a telephone receiver, but it is found in practice to be not nearly so sensitive.

The action of the loose contact seems to be that under the influence of the spark the resistance of the circuit is changed without actually cohering the points and thus no decohering mechanism is necessary. This variation in the resistance causes an audible signal to be given out by the telephone. The signals consist of a succession of short or long buzzes, or musical tones, corresponding to the interruptions of the primary of the induction coil at the sending station.

In practice various forms have been employed for these loose contacts, such as two spheres, a sphere on a plate, a point on a plate, two or three points on a plate, or a kind of gridiron arrangement of bars crossing at right angles. In each case the principle is the same; that is, a change of resistance between the points of contact under the influence of the electric spark. A local circuit with telephone receiver is always used in connection with this loose contact or microphone, and the signal is received by telephone as a succession of short and long buzzes corresponding to the dots and dashes of the Morse code. It has been proposed by some inventors to effect a mechanical tuning in addition to the electrical tuning when using a telephone receiver by making the diaphragm of the telephone respond only to a certain velocity of the circuit-breaker in the primary of the induction coil at the sending station. Prof. Fessenden, working under the direction of the United States Weather Bureau, has lately exhibited an apparatus using a telephone receiver but employing an entirely different apparatus for varying the current strength and thus producing audible signals. Unfortunately I am not at liberty to explain his devices, but I believe that in some respects his apparatus is more reliable than that of other inventors. It was pointed out above, when speaking of coherer receiving apparatus, that the difficulty so far experienced in successfully tuning different sets seemed to be due in a certain measure to the high resistance of the coherer circuit and the amount of energy necessary to break down this resistance. We might expect to be more successful in tuning apparatus in which a microphone and telephone receiver are used, as the resistance in the local receiving circuit in the latter case is not nearly as high as when using a coherer. Recent reports seem to show that this is the case, and that selective signaling can be carried on between several different sets of transmitters and receivers in the same vicinity without interfering with one another. The great defect of the telephonic receiving apparatus has been the need of an efficient calling-up signal, and it is possible that the wireless apparatus of the future will take the form of a combination of the two kinds of receiving apparatus, in which a coherer will be used in connection with a relay and electric bell for calling up, and a telephone receiver switched in for receiving the message. Such an arrangement would have many advantages, the most important being the greatly increased speed of sending and receiving possible when using a telephone receiver, and at the same time the present unreliability of the coherer would not be so disadvantageous when its use was confined solely to calling up, or rather to detecting a call from another station.

There is another kind of receiving apparatus sometimes used, differing from either of those mentioned before. In that, an anti-coherer is employed in place of the coherer, and this is used both with a relay and Morse recording apparatus and also with a telephone receiver. The action of the anti-coherer is exactly opposite to that of a coherer. Under normal conditions a certain resistance is maintained in the anti-coherer circuit. Under the influence of an electric spark this resistance is increased. The silvering on an ordinary glass mirror, if scratched with a sharp point so as to separate the silvering into two portions, becomes an anti-coherer when these separate portions are connected up electrically in a receiving circuit. Under the influence of an electric spark the resistance to the flow of current across the scratch is increased. Other forms of anti-coherers have been invented. It is thought, however, that none of these has proved as reliable in practice as the coherer or loose contact.

Having thus briefly described in a general way the apparatus employed by different makers and inventors, I would like to point out what has actually been done, and what we expect to do, in the way of actually installing wireless telegraphic apparatus on board naval vessels. In the first place the masts of all ships are now being altered and prepared for the installation of wireless apparatus. This is a work of some magnitude as it necessitates increasing the height of the masts from about 120 feet to about 135 feet. The old height of 120 feet had been fixed as the maximum which could safely pass under Brooklyn Bridge. Of course, in the new arrangement, provision is made for housing the mast for this purpose. The upper portion of the mast, at least 50 feet, is of wood and is stayed with hemp rigging, or, in the case of rigging coming lower down than 15 feet from the masthead, it may be of wire set up with hemp lanyards.

Wireless telegraphic masts have also been erected at the Navy Yard, Washington; at the Naval Academy, Annapolis, and are being erected at the Navy Yard, New York, the Naval Station, Key West, and at Dry Tortugas. It is proposed to test thoroughly all the various kinds of wireless telegraphic instruments at these several shore stations and on board naval vessels, and after determining upon the system best adapted to varying service conditions, it will be adopted as the standard for the service and all naval vessels will be supplied with it.

It is needless to point out how greatly this new system of signaling will facilitate fleet maneuvers and operations, particularly in the way of supplying and communicating information gained by scouts, and the greatly enlarged field of action in which a single commander may, at all times, be promptly supplied with all important information, and may at the same time control and distribute his fleet to the best advantage.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York. May 28th, 1902.

ELECTRICITY IN THE NAVY.

BY LIEUT. HARRY GEORGE, U. S. NAVY.

The recent progress in the application of electricity to naval purposes has been very marked. It would be well to sketch the development of this form of energy in the naval service and its numerous applications both for lighting and power in recent years, and to conclude a brief historical summary by a comparison of our own vessels with those of foreign navies.

The advantages of electricity on board ship from a military point of view have long been recognized, particularly with regard to the incandescent lamp and the electric projector. In the old installations these features were alone considered, and anyone having experience with electric lights on shipboard will testify to their advantages over the old method of illumination; less liability to fire, reduction in radiant heat, greater illuminating power, no smoke or disagreeable odors, and no vitiation of the atmosphere by the consumption of oxygen, all these advantages adding greatly to the efficiency of the ship and the health, comfort and cheerfulness of the personnel.

The U. S. S. *Trenton* was the first man-of-war in the world to be lighted by the incandescent lamp. This installation was made in 1883, and consisted of a single dynamo, supplying current to 238 lamps, with a total candle power of 3090. The installation of the electrical apparatus of the ship was superintended by Lieut.-Commander R. B. Bradford, now Rear Admiral and Chief of the Bureau of Equipment. This officer became executive of the vessel, and has been closely identified, both officially and from personal interest, with the development of electricity in our navy.

The lighting of the *Trenton* proved a success and was in operation for a full three years' cruise, and confirmed the opinion that no modern vessel is complete without a plant for lighting by electricity.

The proved efficiency of the *Trenton's* installation and the valuable experience gained in that vessel led to the application of electricity for lighting other vessels. The ships authorized by Act of Congress in August, 1882, viz., the *Dolphin*, *Atlanta*, *Boston* and *Chicago*, were so equipped, and since that time an electric plant has been looked upon as an essential feature of all vessels of war, and the scope has been extended to include both lighting and the electric drive of numerous auxiliaries which have hitherto been controlled by steam or hydraulic power.

The early ships were provided with one generator, hence in case of breakdown it was necessary to have recourse to oil lamps. The specifications for the next vessels, authorized by Act of Congress in 1885 and 1886, called for two complete plants, each an exact duplicate of the other. This was not decided upon without some opposition. It was proposed originally to install two generators, one of large capacity to supply the night load and a smaller one to furnish current for lamps required during the day. This idea was finally abandoned on account of the possible overpowering of the smaller dynamo by the large one, unless carefully watched, the decreased relative economy of small generators, and the diminished number of spare parts necessary in a duplicate installation.

The standard voltage on board our ships until recently was 80 volts, a standard adopted by several foreign services. Recently the standard has been changed from 80 to 125 volts, and the latter voltage is to be used in the majority of the vessels now under construction and in all future installations. The considerations that led to this change and the advantages accruing therefrom are discussed by an officer who presents a paper on the subject at this meeting, and who served as a member of a special board ordered by the Navy Department to decide on the voltage best adapted to naval purposes

Under the old regulations the electrical illumination of a ship came under the cognizance of the Bureau of Navigation, and the searchlights with their accessories under the Bureau of Ordnance, and separate generators were installed for these purposes. At present, all generators are installed by the Bureau of Equipment, which also includes under its cognizance searchlights, wiring, conduit fixtures, switchboard, dynamo-room fittings, wiring appliances and supplies, and accessories and instruments necessary for the care, maintenance and preservation of the electric plant.

Each bureau installing electrically operated machinery has cognizance of and installs the motors and controlling apparatus for this purpose. It is thus seen that the electrical installation of a ship falls under the control and supervision of the Bureau of Equipment, Bureau of Construction and Repair, Bureau of Ordnance and, to a more limited extent, the Bureau of Steam Engineering.

The advantage of the electric drive for auxiliaries appears to be as evident as the superiority of the incandescent lamp over the oil lamp or candle for illumination. The confidence engendered by the use of electricity in the early ships and the rapid commercial development of motors and their controlling apparatus gave an impetus to the use of the electric drive on shipboard, and at the present time we find motors installed for ventilating blowers, ammunition hoists, turret-turning, elevating and loading of guns, workshop machinery, and the handling of boats and heavy weights. Steam or hydraulic power for auxiliarydriving has been relegated to the background, and the day is not far distant when auxiliary machinery of all descriptions will be operated by electricity.

The motor is peculiarly well adapted to naval use. Compared with steam, the cutting of bulkheads and decks is reduced to a minimum, and hence the water-tight system is more efficient, the circuits may be better protected than in the case of steam pipes and offer a smaller target. The cutting of a circuit by shot involves no danger to the personnel, and to surrounding appliances, and in case of accidents is more readily repaired. There is no leak from joints and valves, and no appreciable loss of energy in elbows and turns, no loss by condensation, and much less by radiation. The motors are also more efficient and there is relatively less loss in small motors than in small steam engines; they are less likely to get out of order; there are no reciprocating parts to adjust and their operation is simpler and requires less supervision.

The advance of electricity for naval purposes may be illustrated by a comparison between the electric plant of the *Indiana* one of our first battleships, completed and commissioned in 1895, and that of the *Kearsarge*, one of our latest battleships, commissioned in 1900. The displacement of the *Indiana* is 10,200 tons, and she is equipped with three 24-kilowatt, 80-volt generators for supplying current to 500 incandescent lamps, four 60-centimetre searchlights, two 2 h.p. ventilating motors for dynamo-room, four ½ h.p. portable ventilating blowers, with winches and ammunition hoists, covering about 36 h.p., or a total output of 67 kilowatts, about 7 watts per ton of displacement.

The *Kearsarge*, with a displacement of 11,525 tons, is provided with seven 50-kilowatt generators, compound-wound, direct-connected, 80 volts, to supply the following demand for lighting and power:

	WATTS.
700 incandescent lamps	48,000
4 30″ searchlights	6,000
Ventilating motors and portable fans	98,000
Ammunition hoists and whips	115,138
Training, elevating and rammer motors	171,580
Boat-cranes and winches	216,350

a total of 655,240 watts, or approximately 57 watts per ton of displacement.

In this connection the practice abroad is shown in representative vessels of the German, Russian and French navies:

GERMANY.

Furst Bismarck:—Battleship, 10,650 tons displacement, with an electric generating plant of 325 kilowatts output, supplying current to 900 incandescent lamps, 44 motors for ventilation, drying-room, ammunition hoists, gun-training gear, coal winches, refrigerating plant, and searchlights.

Kaiser Frederick III.—Armored cruiser, 11,130 tons displacement. Five generators, with output of 324 kilowatts supplying power in watts as follows: Incandescent lighting, 38,260; searchlights, 55,500; ventilation, 28,340; ammunition hoists, 78,440; gun-training gear, 8,880; coal winches, 7,400; refrigerating plant, 4,500.

RUSSIA.

Retvizan:—Battleship built at Cramp's Shipyard, Philadelphia, Pa. Electric installation, three 132-kw., four 66-k.w. and one 60-k.w. generators with a maximum output of 588 kilowatts. These generators supply current to 1167 incandescent lamps six 30″ projectors, and the following auxiliaries:

4 turret-turningmotors,
4 elevating motors.
4 rammer motors.

4 turret ammunition hoists.
12 60″ blowers for forced draft system.
18 motors for hull ventilation.
6 pump motors.
2 boat-crane motors.
1 capstan motor.
8 ash hoist motors.
1 steering motor.
30 ammunition hoist motors for battery.
2 submerged torpedo motors.
1 workshop motor.
1 torpedo lathe motor.
1 bread-mixing motor.
1 laundry motor.

Also a number of portable fans, helm indicators, and other electrical signaling devices.

FRANCE.

Jena:—Battleship. Displacement 12,052 tons. Two generators of 98.4 k.w. capacity, and two of 49.2 k.w. capacity. Total output, 295.6 kilowatts.

The general subject of electrical installations will be taken up under the following headings: Dynamo-rooms and Accessories, Generators, Circuits, Wire and Wiring Appliances, Motors, Interior and Exterior Signaling or Communicating Systems, Searchlights and Incandescent Lamps.

DYNAMO-ROOMS.

For security in time of action, the dynamo room is located below the water line underneath the protective or armored deck, in close proximity to the source of steam supply. The chief considerations are protection, ventilation, accessibility, and a central position for the economical distribution of electrical energy. The compartment assigned to the dynamos may be a single one between transverse water-tight bulkheads, or may consist of two or more such compartments in the larger vessels. Fig. 1 shows the general arrangement of dynamos in the U. S. S. *Alabama*, in four dynamo-rooms between two transverse water-tight bulkheads. This plate also shows the arrangement of steam and exhaust piping. The dynamo room is generally provided with its own ventilating system and contains the switchboards, searchlight panels, rheostats, tool boards, work benches, oil and waste tanks, and the accessories necessary for the efficient operation of the plant.

The generators are mounted on light steel foundations, consisting of plating, angle and channel bars, with a yellow pine or teak backing, and are further braced by stanchions tying the flat or platform to the protective deck above, and stanchions bracing to the deck below, with such other stiffening bars and braces as may be found necessary to reduce vibration to a minimum.

Heretofore the dynamos have been located in the same portion of the vessel. the dynamo-rooms forming subdivisions of one general compartment between transverse water-tight bulkheads. The rapid development of the electric drive and its application to ammunition hoists and gun operation has made the

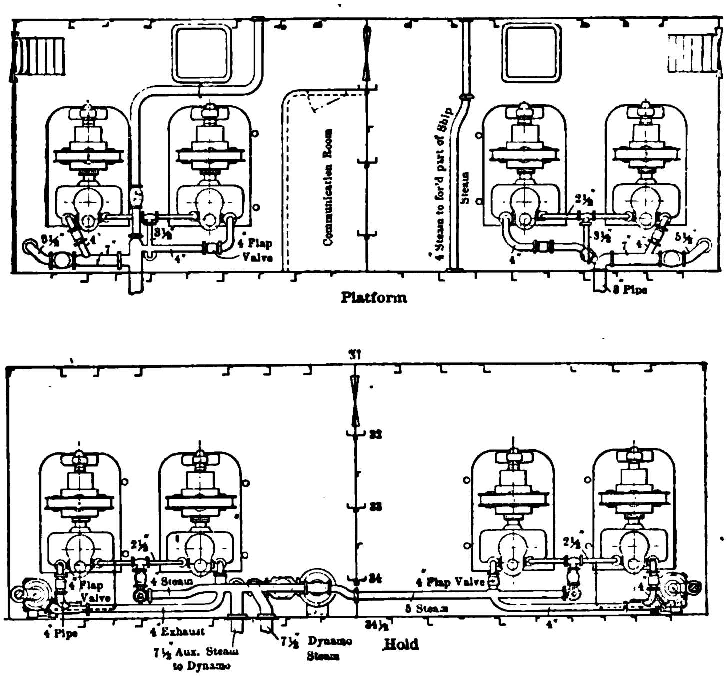


FIG. 1.—Arrangement of Steam and Exhaust Pipes in Dynamo Room, U. S. Battle Ship *Alabama*.

question of dynamo-rooms and their location one of the most important in ship design. In the proposed 16,000-ton battleships recently authorized by Congress, it is proposed to install the generators in two separate compartments, the dynamo-rooms to be entirely independent of each other electrically, and to be situated at opposite ends of the vessel. Each dynamo-room is to be supplied with four 100-k.w. sets, which will supply the output necessary to handle the battle load, for lighting and all auxiliaries. All forward circuits will be supplied by adis[illegible] buting board located near the forward dynamo-room but separated from it; all after circuits from the after distribution board, similarly situated. By suitable transfer switches both the distributing boards may be electrically connected and the entire load thrown into either dynamo-room at will. This will increase the military efficiency of the installation, as in case of accident rendering either dynamo-room uninhabitable, the battle load may be thrown on the remaining room.

ENGINES AND DYNAMOS.

The generating set of the *Trenton* above referred to, consisted of a horizontal Armington and Sims 9½" by 12" simple engine, belted to an Edison under-type dynamo, and although heavy and cumbersome as compared with generators of the present type, it gave good and efficient service. The dynamo was shunt wound, 100 volts, 120 amperes and rated as a 150, 16 c.p. light machine. Belted sets were installed on several vessels up to the latter part of the 80's, when direct-connected sets first made their appearance.

The Edison under-type dynamos were found to produce an effect on the ship's compasses, owing to magnetic leakage and large stray field, a defect which has been entirely obviated by the use of multipolar or ironclad types of generators.

The early direct-connected sets had horizontal engines and by ingnieous design were fairly compact and not excessive in weight. The disadvantages were inefficiency in steam consumption, inaccessibility for repair and cleaning, and excessive vibration.

In 1889 horizontal engines were abandoned in favor of the vertical type. The first vertical engines were two cylinder noncondensing, designed for an initial steam pressure of 80 pounds, cranks at 90°, but the pounding which resulted made necessary the spacing of 180° between cranks in subsequent designs.

The dynamos direct connected to these engines were 4-pole machines with field coils on the vertical and horizontal axes bringing the lower field coil into a position where it was subjected to oil and water, and much trouble was experienced with this coil in this arrangement of poles.

The valve chests were located between the cylinders, mainshaft bearings being provided between the cranks and eccentrics, thus giving five bearings to the sets, four on the engine proper and one on the commutator end of the shaft. The latter bearing was of the self-oiling ring type, the others being lubricated by oil cups. Oval wear in the cylinders developed in these sets, due to rocking of the piston, *i. e.*, lateral play, existing in the cross heads. This was at first remedied by the use of tail rods and later by a new design of crossheads and guides, and the use of conical pistons. The engine and armature shafts were in common, and it was almost impossible to remove and replace the armature without springing the shaft. The defects developed in service in these sets were soon overcome, the poles were spaced diagonally on the field frames and the engine and dynamo shafts were no longer made combination, but joined by flanged couplings securely bolted, and the driving communi-

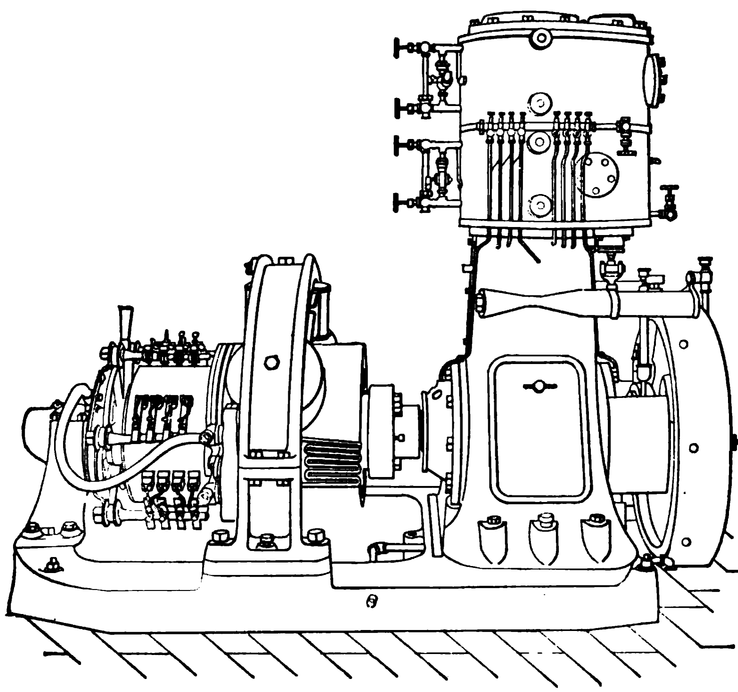


FIG. 2.

cated by a cross-key through a key-way common to both faces of the shaft flanges.

Tandem compound engines have been used extensively and were first installed on the U. S. S. *Chicago*. They are shown in Figs. 2 and 3. They have given excellent results, although not as efficient noras accessible as the cross-compound engine required by the present specifications. The excessive height of this type of generator, not only assembled, but the additional head-room necessary to remove pistons and rod, prohibits their use in naval installations with the comparatively small height between decks. Fifty kilowatts would seem to be the maximum capacity allowable in generators of this design, and they could only be used in a majority of vessels by making special provision for the removal of pistons.

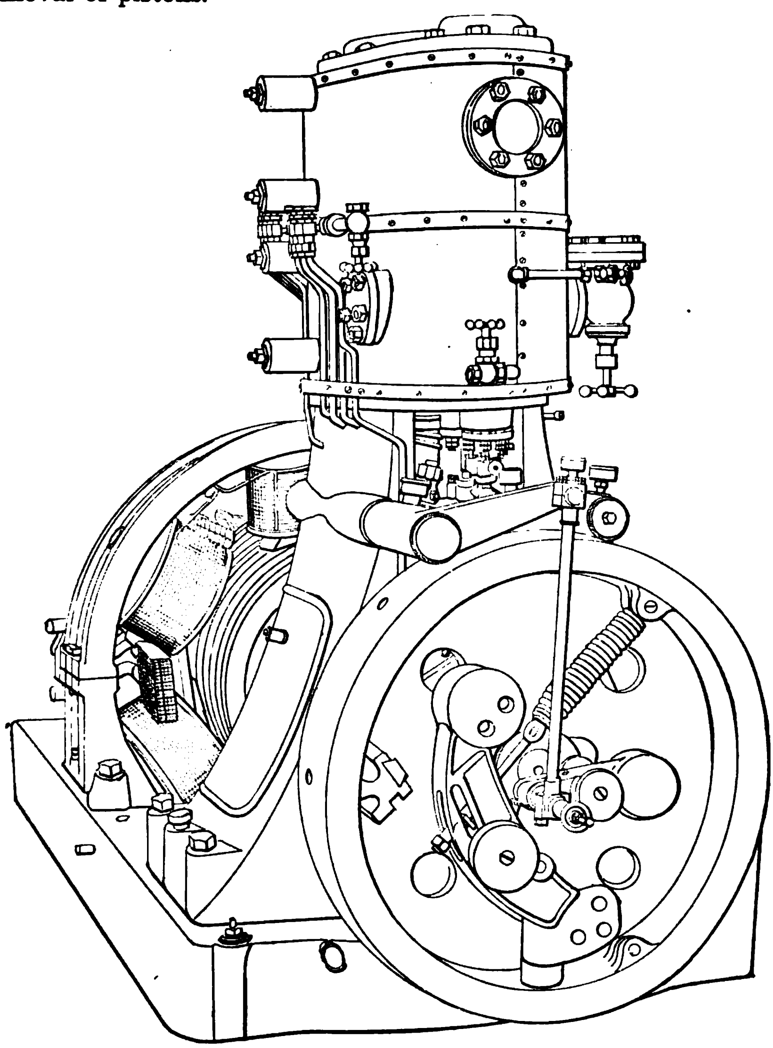


FIG. 3.

Lubrication in the steam spaces is not allowed, as the auxiliary boilers in some cases have been injured and the crown sheets dropped in spite of the precaution of removing oil from condensed steam. To lessen further the liability of oil working into the cylinders, the stuffing boxes are specified to be at least as long as the length of stroke of engine. These boxes are to be accessible from the outside of the enclosing casing of the engine to facilitate adjustment.

Forced lubrication is an essential factor in attaining satisfactory operation of a generator, and is now required on all sets furnished the navy. A pressure of from 10 to 20 pounds is prescribed in the lubricating systems, but the bearings are to be so designed that forced lubrication is not a necessary feature to insure cool running.

The smaller sets, 2½ and 5 k. w., for torpedo boats and destroyers are designed for high speed, in order that reduction in weight may be attained. This involves a rather uneconomical steam consumption, but inasmuch as these sets are not subjected to continuous running, as in battleships and cruisers, the increased weight of steam required for their operation is not considered in the attempt to reduce all torpedo boat weights to a minimum.

The 2.5 k. w. sets give an output of 5 watts per pound, the 5 k. w. sets 3.865 watts per pound, although some 5 k. w. sets have been installed with an output of 5 watts per pound weight of set.

The 16-k. w. sets, although of comparatively high speed (400 to 500 r.p.m.) show a weight efficiency rather lower than would appear consistent with other types. These sets give 2.86 watts per pound, whereas the 32 k. w. sets give 3.14 watts and the 100 k. w. sets 4.55 watts per pound. The specified water consumption of all sets is rather liberal, as it is the aim to secure fair efficiency with great durability, and sacrifices are made to ensure the latter characteristic in naval installations.

Generators have improved step by step with the commercial type, and the specifications now in force embody no requirements that are not fulfilled by the best types of commercial machines, excepting that the rating of these generators must be changed to conform to the specified heating limits and overload requirements. An allowable temperature rise of 33⅓° C. in armature appears at first sight rather low, but taking into consideration the high temperatures in many of our dynamo-rooms in tropical service, the low heating limits assigned are justifiable.

A two-hour overload of 33⅓% is specified in order that a machine running at or near full load may be capable of handling a sudden call for a motor load or searchlight, thus obviating the delay caused by being compelled to start a new machine.

The present specifications issued in November, 1901, based on experience, are outlined as follows:

Each set to consist of an electric generator direct-coupled to a steam engine, both mounted on a common bed-plate.

The sets as a whole shall be as compact and light as is consistent with a due regard to strength, durability, and efficiency. The standard sizes with their corresponding maximum allowable speeds, weights and over-all dimensions are:

TABLE 1.

Size in kilowatts.	Revolutions per minute.	Weight in pounds.	Length in inches.	Width in inches.	Height in inches.
2.5	800	500	32	20	30
5	750	1,300	50	28	40
8	550	2,500	64	34	50
16	450	5,600	78	40	60
24	400	7,300	88	48	68
32	400	10,000	101	52	78
50	400	16,000	110	60	85
100	350	22,000	125	70	95

The design shall provide for accessibility to all parts requiring inspection during operation, or adjustment when under repair. Sets are to be designed to operate right-handed, *i. e.*, counter clockwise when facing the commutator end, or left-handed, as required. The design to be preferably such that the same parts may be used in each, in order to avoid increase in number.

The sets must be capable of running without undue noise, excessive wear, or heating. Must be balanced and run true at all loads up to 33⅓% above rating; must be capable of running for long periods under full load and without continued attention.

Cast or wrought iron shall not be used for bearing surfaces, except in cases of cylinders, valve chests, and crosshead slides. Both upper and lower halves of main bearings to be removable without removal or displacement of shaft.

The driving shaft must be fitted with thrust collars or other suitable device which will prevent a movement of the shaft in the direction of its length, as might be caused by the rolling of the ship.

The combination bed-plate to be a substantial casting, and provided with accurately spaced drilled holes for securing to foundation.

An oil groove of ample width and depth to be cast in the upper flange of bed-plate, to be continuous around the engine and to be provided with a stopcock for drainage. The lower side of the combination bed-plate to be planed perpendicular to the line of stroke of engine.

Seats for all boltheads and nuts to be faced. All nuts to be case-hardened, and to be U. S. standard sizes. Where liable to work loose from vibration, nuts are to be secured by use of jam nuts and spring cotters. All bolt ends to be neatly finished. The two halves of the main coupling to be either keyed to, or forged solid with the engine crank and armature shaft. The coupling to be bolted together by well-fitted bolts, driving to be done by a cross-key set in the faces.

ENGINE.

Engines are to be of the automatic cut-off vertical inclosed type, designed to run condensing with maximum practical efficiency at all loads, but capable of satisfactory operation when running non-condensing; to be of sufficient indicated horsepower to drive the generator for an extended time at the rated speed, when said generator is carrying a one-third overload.

Sizes 2½ k. w.,5 k. w., and 8 k. w., to be simple engine, single or twin cylinder at the option of the contractor. Sizes of 16 k. w. and above to be cross-compound with cranks set at 180°.

The normal steam pressure under which the engine, running condensing with 25-inch vacuum for different size sets, is to operate, and the maximum allowable water consumption per kw. hour output of the set are:

TABLE 2.

K.W.	Normal steam pressure.	Water consumption per K.W. hour, full load.
2.5	100	105
5	100	90
8	100	65
16	100	44
24	100	40
32	100	37
50	100	35.5
50	150	33.5
100	150	31

In testing, correction shall be made by calorimeter for entrained moisture. Superheating shall not be used in the test.

Engines must run smoothly and furnish the required power for full load at any steam pressure within 20% (above or below) of those given above and exhausting either to condenser at 25 inches vacuum or to the atmosphere. Must be able to bear without injury the sudden throwing on or off of one and one-third times the rated full load of the generator, by making and breaking the generator's external circuit.

The length of stroke of the engine to be not less than the diameter of the bore of the high-pressure cylinder.

The cylinders to be made of hard, close-grained charcoal iron, bored and planed true, of sufficient thickness for operation after re-boring once, steam and exhaust ports to be short, of ample area and free from fins, scales, sand, etc. Cylinders to be fitted with the usual drain cocks, all drains to end in one outlet. In addition to these drains, relief valves are to be fitted to each end of each cylinder, and both high-pressure and low-pressure valves are to be free to lift from their seats to relieve the cylinder of water.

The low-pressure cylinder must be fitted with a flat, balanced slide valve; a piston valve on the low-pressure cylinder will not be accepted.

The pistons to be of cast iron or steel, strongly ribbed, light and rigid, and fitted with self-adjusting rings, each piston to have two or more rings. Rings to override counterbore of cylinders, to prevent wear to a shoulder.

Piston rods to be of forged steel securely fastened to pistons and crossheads. Crossheads to be of steel with adjustable shoes. Connecting rods to be of steel with removable babbitt-lined boxes for crank pins and bronze boxes for crosshead pins.

The crank shaft to be forged in one piece; counterweights for balancing reciprocating parts to be forged with it or securely fastened thereto. Valve rods, eccentric rods, and rocker shafts, as well as all finished bolts, nuts, etc., to be of best forged steel.

The governor to be of the weight and spring type, arranged to operate the high-pressure valve by a shifting eccentric, thus automatically varying the valve travel and point of cut-off. No dash-pots or friction washers shall be used in its construction.

The speed variation must not exceed 2½% when load is varied between full load to 20% of full load, gradually or in one step, engine running with normal steam pressure and vacuum. A variation of not more than 3½% will be allowed when full load is suddenly thrown on or off the generator, with constant steam pressure either normal, 20% above, or 20% below normal, and exhaust either to condenser or to atmosphere. No adjustment of the governor or throttle valve during the test shall be necessary to ensure proper performance under any of the above conditions.

Stuffing boxes for piston rods to be slightly longer than length of stroke, in order that no part of the rod exposed to the oil in the enclosure will enter the cylinders. Stuffing boxes for piston rods and valve rods to be accessible from the outside of the enclosing case of the engine.

A guard plate to be provided to prevent oil from being thrown against the lower cylinder heads and valve chests.

Engines are required to operate satisfactorily without the use of lubricants in the steam spaces. The lubrication for all other working surfaces shall be of the most complete character. No part shall depend on squirt-can lubrication.

Forced lubrication shall be used wherever practicable, which includes engine shaft, crank pins, crosshead bearings, eccentric, etc. The engine shall be capable of satisfactory operation with a low grade of lubricating oil, and the forced lubrication shall not be a necessary factor for its cool and satisfactory running. The intent of the forced lubrication is to reduce friction, noise and attention required.

The pressure for such forced lubrication shall be approximately 15 pounds per square inch, and shall be between 10 and 20 pounds under all service conditions.

The bed-plate is to contain a reservoir and cooling chamber of ample capacity, to be provided with a strainer which may be removed without interrupting the oil supply. The pump is to be direct-driven by a crank or eccentric on the engine shaft, construction to be simple and durable, and to include a proper guide or support for the plunger rod. The pump to handle clean oil only, not drawing from the top or bottom of reservoir.

GENERATOR.

To be of the direct current, multipolar type, compound-wound long-shunt connection, designed to run at constant speed and to furnish a pressure of 125 volts at the terminals, at rated speed, with load varying between no load and one and one-third times rated load.

The magnet yoke or frame to be circular in form, to have inwardly projecting pole-pieces, and to be divided in half horizontally, in all generators above 5-k.w. capacity, the two halves being secured with bolts, to allow the upper half with its pole pieces and coils to be lifted to provide for inspection or removal of armature. Pole pieces to be bolted to frame, bolts to be accessible in assembled machine to enable removal of field coils without disturbing armature or frame. Magnet frame to be provided with two feet of ample size to ensure a firm footing on the foundation.

Facilities for vertical adjustment of frame to be provided in sizes of 16 k.w. and above.

Armature spider to be designed to avoid shrinkage strains; to be accurately fitted and keyed to shaft and to have ample bearing surface thereon.

The disks or laminations to be accurately punched from the best quality of thoroughly annealed electrical sheet steel, slots to be punched in periphery of laminations to receive armature windings. Disks to be magnetically insulated from one another, and securely keyed to spider or held in some other suitable manner to obviate all liability of displacement due to magnetic drag, etc. Space blocks to be inserted between laminations at certain intervals to provide ventilating ducts for cooling the core and windings.

Laminations to be set up under pressure and held securely by end flanges. Bolts holdings these end flanges must not pass through laminations.

The commutator bars or segments to be supported on a shell, which must be either part of, or directly attached to the spider, to prevent any relative motion between the windings and these segments. Bars to be of hard drawn copper finished accurately to gauge. Insulation between bars to be of carefully selected mica and not less than 0.03 inch thick, and of uniform thickness throughout.

Bars to line with shaft and run true, to be securely clamped by means of bolts and clamping rings. Bolts to be accessible for tightening and removable for repair.

Brushes to be of carbon. In sizes over 5 k.w. there shall be not less than two brushes per stud, each brush to be separately removable and adjustable without interfering with any of the others. The point of contact on the commutator shall not shift by the wearing away of the brush.

Brush holders to be staggered in order to even the wear over entire surface of commutator; the generator to be provided with some device for shifting all the holders simultaneously. All insulating washers and brushes to be damp proof and unaffected by temperature up to 100° C.

Finished armature to be true and balanced both electrically and mechanically, that it may run smoothly and without vibration. The shaft to be provided with suitable means to prevent oil from bearings working along to armature.

All copper wire to have a conductivity of not less than 98%.

The shunt and series field coils to be separately wound and separately mounted on the pole-pieces. The shunt and series coils, respectively, of any one set to be identical in construction and dimensions and to be readily removable from the pole-pieces.

The testing voltage for sets under 16 k.w. shall be 1,000 volts and for sets of 16 k.w. and above shall be 1,500 volts, and the source of the alternating e.m.f. shall be a transformer of at least 5 k.w. capacity for sets of 50 k.w. and under, and of at least 10 k.w. capacity for sets of greater output than 50 k.w.

The test for dielectric strength shall be made with the completely assembled apparatus and not with its individual parts, and the voltage shall be applied between the electric circuits and surrounding conducting material.

The tests shall be made with a sine wave of e.m.f., or where this is not available, at a voltage giving the same striking distance between needle points in air, as a sine wave of the specified e.m.f. As needles, new sewing needles shall be used. During the test, the apparatus shall be shunted by a spark gap of needle points set for a voltage exceeding the required voltage by 10%.

With brushes in a fixed position there shall be no sparking when load is gradually increased or decreased between no load and full load; no detrimental sparking when load is varied up to one and one-third times rated load; no flashing when one and one-third load is removed or applied in one stage.

The jump in voltage must not exceed 15% when full load is suddenly thrown on and off.

The temperature rise of the set after running continuously under full rated load for four hours must not exceed the following:

TABLE 3.

	Method of measurement.	Maximum allowable rise in °C.
		°
Armature	Electrical	33⅓
Commutator	Thermometer	40
Field coils	Electrical	33⅓
Shunt rheostat	Electrical	75
Series shunt	Thermometer	40

The rise of temperature to be referred to a standard room temperature of 25° C. and normal conditions of ventilation. Room temperature to be measured by a thermometer placed 3 feet from commutator end of the generator with its bulb in line with the center of the shaft.

The generator to be capable of satisfactory operation for a period of two hours, carrying one and one-third times its rated full load, and no part shall heat to such a degree as to injure the insulation.

Generators of the same size and manufacture to be capable of operation in parallel, the division of the load to be within 20% throughout the range. The magnetic leakage at full load shall be imperceptible at a horizontal distance of 15 feet, measurements to be taken with a horizontal force instrument.

The minimum allowable efficiencies of the generators are as follows:

TABLE 4.

K. W.	Loads.			
	1⅓.	1.	¾.	½.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2.5	78	78	76	73
5	80	80	78	75
8	84	84	83	80
16	87	87	86	84
24	88	88	87	85
32	88	88	87	85
50	89	89	88	86
100	90	90	89	87

The cross-compound type of engine now used exclusively in the new installations for sets above 8 k. w. shown in Fig. 4, which gives sectional plans of dynamo engines for the *Wisconsin*, designed and manufactured by the Union Iron Works. Cylinders 8½" and 13½" diameter; stroke 8" r.p.m. 400; initial steam pressure 100 lbs.; h.p. 50; over-all dimensions, length 8' 3.5", width 3' 7", height 6' 3".

Fig. 5 shows multipolar 8-pole, 24 k. w., 400 r.p.m., 80-volt, generating set manufactured by the General Electric Company for the *Olympia*. The details of this generator and the tabulated result of test are as follows: Weight, 9,385 lbs., complete; extreme length 84"; extreme width, 52"; extreme height, 77½" over all; number of cylinders, two; cranks at 180°; inertia governor, steam pipe 2½"; exhaust pipe 4"; diameter high pressure cylinder 7½"; diameter low pressure cylinder 12"; stroke 8".

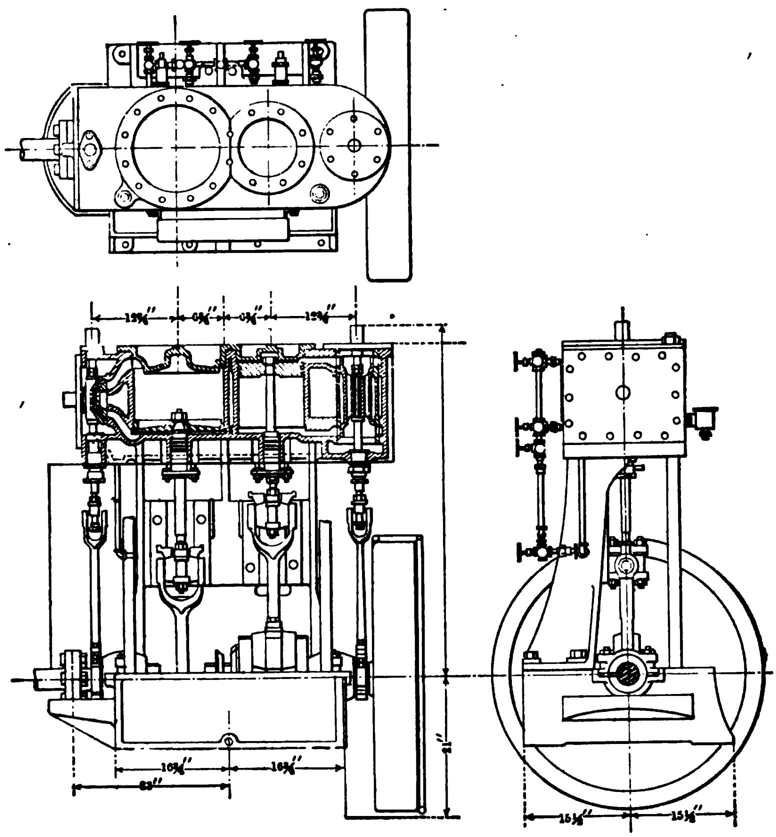


FIG. 4.—Engine 8⅝" x 13½" x 8" stroke for 32 k.w. Dynamo.

Dynamo dimensions: Volts 80°; amperes 400; r.p.m. 400; poles 8; number of carbons per brush 1; dimensions of brushes 1¼" x ⅝".

TESTS.

Heat run.—4 hours at 394 amperes. Terminal volts 81.8 to 81.5; steam 100 lbs; vac. 22 to 21.5; r.p.m. 406; temperature air 28.2° C. at beginning, 30.2° C. at end of run.

Temperature at end of heat run: Armature core surface, 51°C.; commutator bars, 55.5°C.; pole tip leading, 47.5°C.; pole tip trailing, 48°C.; main bearings, 52°C.

Overload run, two hours at 33⅓% overload. Temperature of air during run, 30°C. Temperatures at end of run: armature core surface, 59.5° C.; commutator bars, 59.5°C.; pole tip leading, 53.5°C.; pole tip trailing, 54° C.

Average water consumption during four hour heat run, 33.6 per k.w. hour.

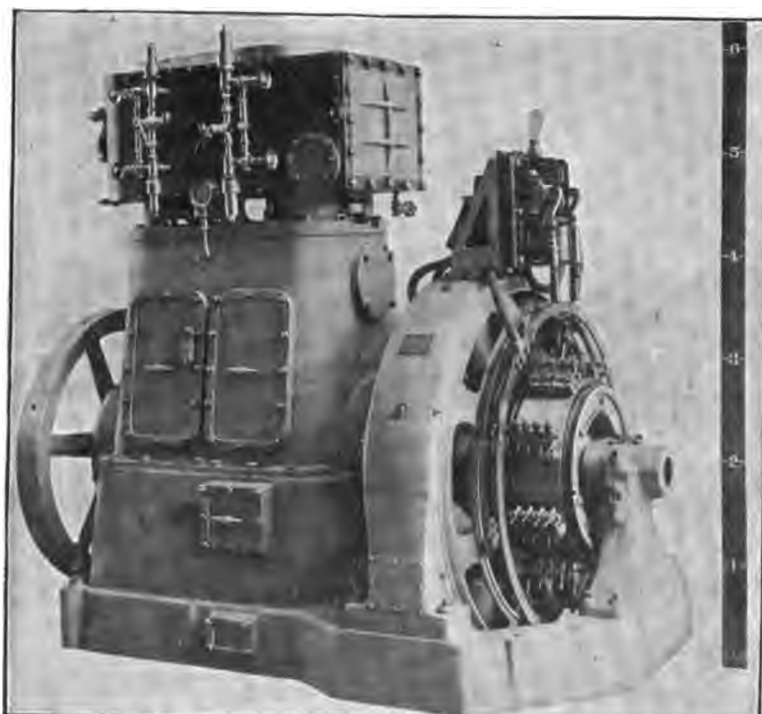


FIG. 5.—MP 8-32-400-80 Volt Form D Generating Set, with 7½"-12" x 8" Cross-Compound Form H General Electric Engine.

OUTPUT AND EFFICIENCY.

I^2R brush, 768 watts.	Volts, 80.
I^2R armature, 1,600 watts.	Amperes, 400.
I^2R series, 422.4 watts.	Input, 32,000 watts
C. E. shunt, 753.3 watts.	
Core loss and friction, 1,637 watts.	Losses, 5,180 watts.
Total losses, 5,180.7.	Outputs, 37,190.7 watts.
	Efficiency, 86%.

TABLE 5.

ENGINE REGULATION. Full load to no load.

Revolutions.			Volts.			Amperes.	Steam.	Vacuum.
Steady.	High.	Low.	Steady.	High.	Low.			
410	435	415	81	91	81	0	100	21.5
415	410	405	81	81	72	400	100	22.0
410	436	415	80.8	92	81	0	100	21.5
415	410	405	81	81	72	400	100	21.5
410	435	415	80.8	91	81	0	100	21.5
415	410	405	81.1	81	72	410	100	21.5

Average difference, 5.
Average difference per cent., 1.25.

TABLE 6.
Compounding Test—Hot.

Armature.		Field.		R. P. M.	Steam.	Vacuum.
Volts.	Amps.	Volts.	Amps.			
81.2	0	64	12.27	415	100	22.5
81	405	64	12.29	410	100	22.5
82.3	303	65	12.49	412	100	22.5
82.6	202	65.2	12.52	415	100	22.5
82.4	101	64.8	12.43	416	100	22.5
81.2	0	64.0	12.29	416	100	22.5
81.2	101	64.0	12.29	414	100	22.5
81.5	202	64.5	12.31	412	100	22.5
81.5	303	64.5	12.32	412	100	22.5
81	405	64.0	12.29	410	100	22.5

SWITCHBOARDS.

Switchboards are designed to give great flexibility to the distribution of electric energy and admit of a variety of combinations of generators. The present boards are more uniform in design than in the old installations, and a standard has finally been adopted which may be used for any number of dynamos.

The design of the switchboard in general is such that any dynamo or combination of dynamos operating in parallel may be run on any circuit or combination of circuits. These circuits are: search-light, light, power, and one for each electrically operated turret, the operation of the turning mechanism of which requires a separate dynamo.

In the larger installations, the switchboard has a generator panel, a lighting distribution panel, a power distribution panel and a searchlight panel. The first three are continuous and form one board, the last is separated from the main board. When the installation consists of two generating sets only, the lighting distribution panel and power distribution panel, and, when space permits, the searchlight panel may be combined.

The switchboard is arranged for connecting the negative lead of each machine to a horizontal common negative bus-bar, by a single-pole, single-throw switch. When the dynamos are more than three in number, each one is arranged for connection to either of two horizontal equalizer or bus-bars by means of single-pole, single-throw switches. For installations of three dynamos only, one equalizer bus-bar is necessary, and for two dynamos a single equalizing switch is used.

The positive lead of each dynamo connects to a vertical bus-bar. The circuits, five in number, each lead from a separate horizontal bus-bar. At each crossing of these two sets of bus-bars (the number of points will be the product of the horizontal and vertical bus-bars), connections can be made by means of single-pole, single-throw switches, placed horizontally. Switches all hinge from dynamo bus-bars and throw to the left.

The arrangement of the dynamo panel is such that all the switches and instruments (except voltmeters) necessary for the control of one dynamo are in a vertical line, and consists of (starting from the top) a single-pole automatic circuit-breaker, an ammeter shunt, an ammeter handle for operating field regulator, voltmeter receptacle, such field controlling switches as the turret turning system requires, positive dynamo switches connecting to circuit bus-bars, switch to common negative bus-bars, switches to equalizer bars, and last, a switch for shunting around the series field of dynamo when turret turning system so requires.

The arrangement of the voltmeters allows the voltage of any dynamo to be read on either of two voltmeters, allows all the voltmeters to be interconnected for calibration and allows the simultaneous reading of the voltage of any or as many dynamos as it may be desired to connect in parallel at any one time.

The power distribution panel contains a double pole switch, fused, for each motor circuit, a main negative power switch, a main negative switch for each turret-turning circuit,and such other auxiliary switches as the turret-turning system may require.

The light-distribution panel contains a double-pole switch, fused, for each lighting circuit, a main negative lighting switch, and when a separate searchlight panel is used, the light distribution panel contains a main negative searchlight switch.

The switchboard is to be provided with a lamp ground-detector with a switch for breaking ground connection. In addition, a voltmeter ground detector is to be provided with leads to a selective plug receptacle to assist in determining circuit which the ground is on. All switches and bus-bars are of hard drawn pure copper, with conductivity not less than 96%. When the hinge carries current,s witches are provided with spring hinge washers, with ready means of adjusting them. All circuits terminate and all connections are made on the back of the board. Name plates are secured to the board near the circuit switches showing the serial number of each circuit and the character and location of its load.

Ammeters and voltmeters for generating sets are marked with the number of the set; ammeters and voltmeters for searchlight circuits are marked with the name and number of the particular light.

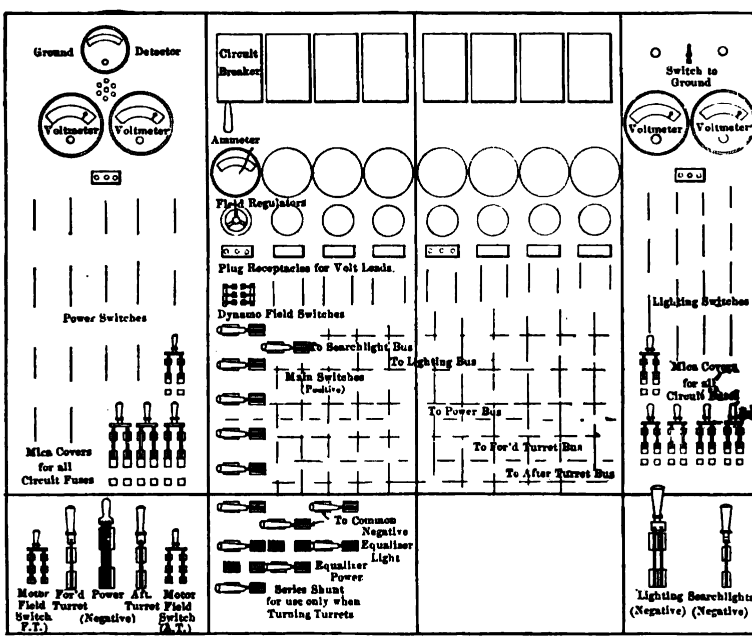


FIG. 6.—Standard Switchboard, 8-Dynamos, 5-Circuit Bus Bars, showing Arrangement and Switch and Instrument Locations.

Faces of slate panels are finished with black enamel. Panels are at least $1\frac{1}{2}''$ thick, supported by a frame of all steel construction and secured thereto by through bolts.

Figs 6 and 7 show the standard switchboard adopted for future installations. This board is similar to the type to be installed in the *Maine*, *Missouri* and *Ohio*. The circuits are five in number, including separate circuits for each electrically turned turret. For paralleling the dynamos, there are two separate equalizer bus-bars, one for lighting and one for power.

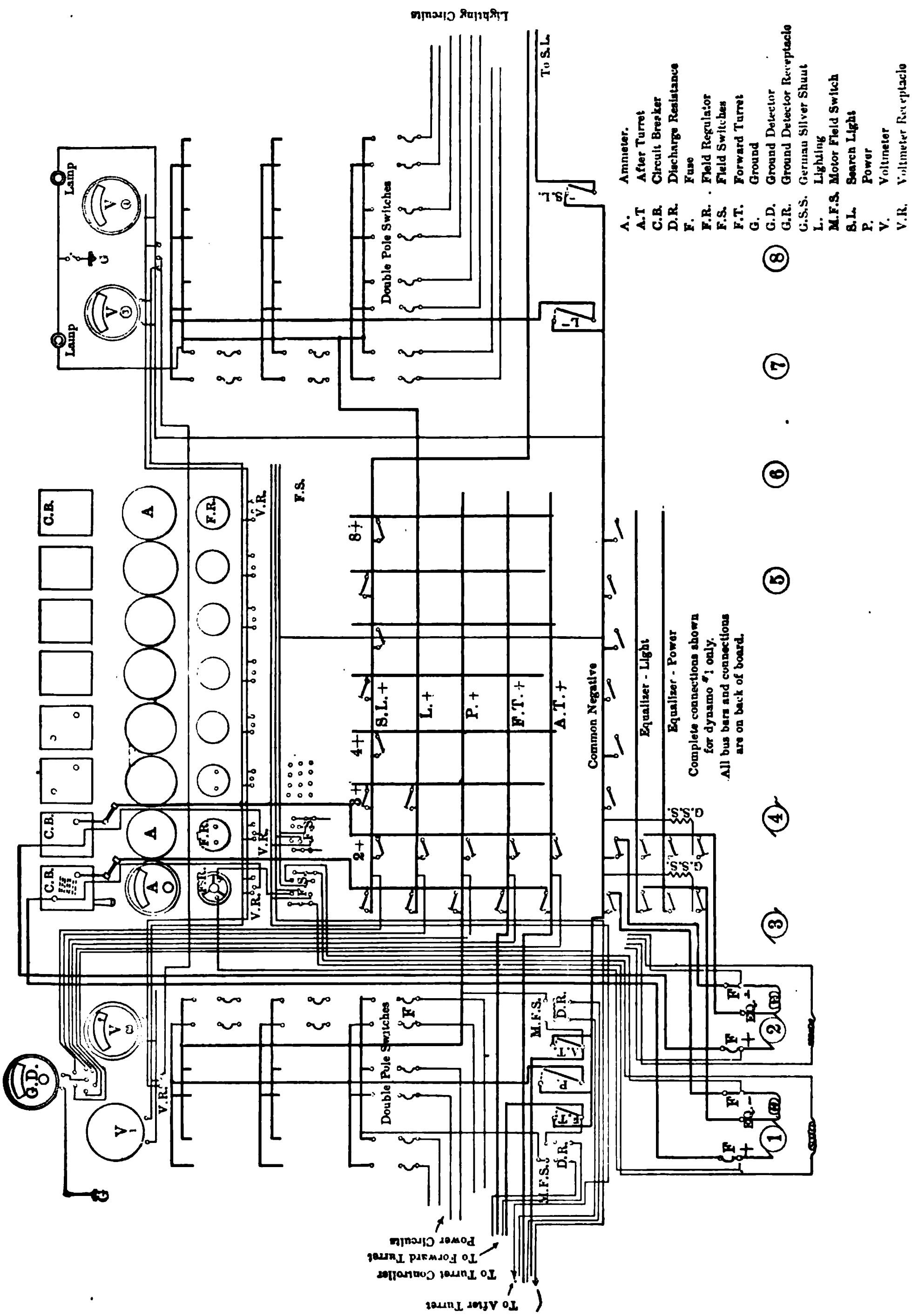


FIG. 7.—Diagrammatic Sketch of Standard Switchboard, arranged for 8-Dynamos and 5-Circuit Bus Bars.

There is no occasion for paralleling machines on searchlight or turret-turning circuits. Such dynamos as may be desired are connected to these equalizer bus-bars by removable blade plug switches.

When a dynamo is used to operate a turret-turning motor, the series field is short-circuited through a special German silver shunt, in addition to the shunt used on the dynamo itself. This is accomplished by a single-pole, single-throw switch at the base of the board, one switch to each machine. Referring to Fig. 6, each of the two dynamo panels is arranged in four vertical sections, each section containing all the apparatus necessary for the operation of one dynamo. Starting at the top, we have a single-pole automatic circuit-breaker on positive leg of dynamo (handle of circuit-breaker not more than six feet from deck), then the ammeter shunt on the back of the board, next the ammeter, then the wheel for operating the field regulator, the wheel being connected to the rheostat by a sprocket chain. Next comes the plug receptacle for voltmeter connections, then field control switches, consisting of three pairs of single-pole, single-throw switches, next five single-pole, single-throw positive dynamo switches, by means of which the dynamo may be connected to searchlight bus, lighting bus, power bus, forward turning bus or after turning bus. In the same vertical row, but on the lower panel, there are four single-pole, single-throw switches; the upper one connects the negative leg of the dynamo to the common negative bus-bar, the two middle switches connect to the equalizing bus-bars; the lower switch is to shunt the series field for turret turning.

At the left of the generator panel is the power distribution panel, containing as many double-pole, single-throw fused switches as may be required. Arranged at the top of this panel is a ground detector with selective plug receptacle, also two voltmeters with plug receptacle underneath. In the center of the power panel is a main negative power switch, single-pole, single-throw, while on each side are two single-pole, single-throw switches controlling the negative legs of the turret-turning circuits. The left hand switch is for the forward turret, and the right hand switch for the after turret. Again outside of these last mentioned switches are the field switches of the turret motors and the dynamos used for turret turning. These are double-pole, single-throw switches, with an extra set of long switch clips, across which is connected a field discharge resistance.

To the right of the generator panels is the lighting distribution panel, containing as many double-pole, single-throw switches as may be required. At the top of this panel is an ordinary lamp ground-detector with a small single-pole, single-throw switch to break the ground connection (this being necessary before using detector on power panel). This panel also contains two voltmeters with plug receptacle underneath. On the lower panel are two single-pole, single-throw main negative switches, one for lighting circuits and the other for searchlight circuits. Each dynamo contains on its headboard a main fuse on its positive leg. The field-control switches allow three methods of field excitation. By throwing the two upper switches, the machine is made self-exciting. By throwing the two middle switches, the machine is separately excited and controlled from the forward turret. By throwing the two lower switches, the machine is separately excited and controlled from the after turret.

The voltmeter connections are shown in Fig. 7. The plug receptacle on the power panel and the four receptacles on the left hand dynamo panel for machines 1, 2, 3 and 4 have a spacing of 1″ and 2″, whereas the receptacle on the lighting panel and those for machines 5, 6, 7 and 8 have a spacing of 1½″ and 2½″. By using the 1″ plug in any receptacle on the dynamo panels, the voltage of the machine is read on voltmeter No. 1; by using the 2″ plug the voltage can be read on voltmeter No. 2; thus we can read the voltage of any two machines on the left-hand panel and of any two machines on the right-hand panel simultaneously. With the 2″ plug in a receptacle on the dynamo panel and the 1″ plug in the receptacle on the power panel we have voltmeter No. 1 in parallel with voltmeter No. 2 for calibration. With the 1″ plug in any receptacle on the dynamo panel, the 2″ plug in the receptacle on the power panel and the 1½″ plug in the receptacle on the lighting panel voltmeters Nos. 1 and 3 are in parallel. By substituting the 2½″ plug for the 1½″ plug in the above arrangement, voltmeters Nos. 1 and 4 are in parallel. As only one plug of each spacing is to be furnished, it is impossible to make a short-circuit or parallel two machines on the voltmeter connections. An inspection of Fig. 7 shows this to be true.

When starting up a new machine to be paralleled with the one already running, the operation at the switchboard is as follows: First, close circuit breaker; Second, close equalizer switch; Third, close switch to common negative; Fourth, plug to voltmeter and adjust voltage by field regulator; Fifth and last, close positive switch.

For detecting grounds, the lamp detector on the upper part of the lighting panel is connected permanently across the common negative bus, and the positive leg on the lighting circuit panel; add when using the ground detector on the power panel, the ground connection on this lamp detector must be broken. The connections to this ground detector (on power panel) are such that when a circuit is grounded on the positive leg, the instrument will indicate when plugged to negative; and for a ground on the negative of any circuit, the instrument will indicate when plugged to any of the positive circuit bus-bars, provided, of course, that said bar is alive, and here it should be noted that a bar is alive when any switch in the horizontal row connecting to it, is thrown.

To locate a ground in the quickest possible manner, the group switches, *i. e.*, main negative and positive dynamo switches on the lighting circuit, should be opened; if the ground still appears the switches should be closed and the corresponding switches on each circuit opened (one circuit at a time) until the ground disappears. When the ground is singled down to one group, the circuit-switches on this group should be opened one at a time until the defective circuit is found.

Circuits, Wire and Wiring Appliances.

Circuits are installed on the main and feeder system. The feeders are connected to terminals on the switchboard and feed the mains as nearly as possible at the center of the load.

All wires for feeders, mains and branches are installed in enameled steel conduit except in passages and dynamo rooms, if not exposed to mechanical injury, when porcelain racked hangers are allowed. Moulding is no longer used except in officers' quarters or over hardwood surfaces, for the sake of appear ances. All feeders as far as possible run below the water line. Thorough water-tightness is observed for all leads into wiring appliances and fixtures and through all water-tight decks and bulkheads.

The conduit is secured to the metal of the ship by stout metal straps, and the wiring appliances are usually supported in place by the conduit. Conduit is made water-tight internally when necessary to prevent the flow of water from one compartment to another. For wire of below 60,000 c.m., cross-section twin conductor is run in the same conduit; above this size, two leads of conduit are used, one for each leg.

Circuits are divided into three classes, each being entirely distinct from the others: (1) searchlight circuits; (2) lighting circuits; (3) motor circuits.

Each searchlight is provided with a separate feeder from the switchboard through a double-pole switch, fused, rheostat, ammeter and double-pole automatic circuit-breaking device direct to the terminal lead of searchlight pedestal. A rheostat in a non-combustible frame is supplied for each search-light. The rheostat has a dead resistance which, when heated, gives a drop of from 55 to 65 volts, and also an adjustable portion in not less than ten divisions, each giving a drop of one volt for the normal current of the lamp. The value of the dead resistance depends on the size of the searchlight, large lights requiring higher voltage across the arc than the smaller ones, and this value is such that with 125 volts on the dynamo side, the variable resistance will give at the search-light from four volts below the best working voltage of the lamp to six volts above the best working voltage The maximum allowable rise in the rheostat is 75° C.

The feeders are of the following sizes:

13″	18,081 c.m.
18″	30,856 c.m.
24″	38,912 c.m.
30″	60,088 c.m.

Lighting circuits are divided into these two classes, each class having separate feeders and separate mains.

(a) Battle service.

(b) Lighting service.

Battle service includes every light installed below the protective deck and all lights above the protective deck which are necessary during action. This includes lights for the operation of guns, at ammunition hoists, boat-cranes, at controllers, ni military tops, on searchlight platforms, in conning tower, in signal tower, in limits, chart-house, signal and running lights, compass light, lights at main blowers above the protective deck, and such light as may be necessary to allow access to compartments and passages in action.

Lighting service includes all lights not above enumerated. The maximum load on lighting feeders does not usually exceed 75 amperes. The area of cross-section of the feeders and mains is such that the fall of potential from the dynamo terminals to the most distant outlet is not more than 3% at the normal load of the feeder. No feeder or main has a cross-section that will give a greater current density than one ampere per 1,000 c.m. All reductions in size of feeders or mains are fused and wherever mains are led off from feeders, it is done through standard feeder junction-boxes, having double-pole fuses, which blow on the basis of one ampere per 500 c.m. of the main. The branch outlets are fused for the normal rated load of three amperes and blow at six amperes. Fuses for feeders and mains are at the rate of one ampere per 1,000 c.m. and blow at one ampere per 500 c.m.

Motor Circuits.—Motors the normal full load circuits of which are less than 50 amperes are grouped on one feeder, and this procedure is followed up to a total load of 100 amperes. Large motors with full working load exceeding 50 amperes are installed with a separate feeder. The area of the cross-section of the feeders for motors is such that the fall of potential from dynamo terminals to motor terminals does not exceed 5% at normal full load.

Mains from motor feeders pass through feeder junction-boxes having double-pole fuses. Where several mains lead from the same feeder at one point a distributing panel with double-pole fuses is installed. All motor feeders and mains have a cross-section of not less than 1,000 c.m. per ampere for continuous service, and 500 c.m. per ampere for intermittent service.

Wire.—The wire used for electric circuits in the early naval installations consisted of a solid copper conductor covered with three layers of cotton braid, the inner one soaked in a bituminous composition, the outer one painted. In addition to the above protection, branch wires were tinned and covered with a rubber coating. This wire proved inefficient, the salt water finding its way to the conductor. To protect the conductor from this action, a lead covering was next introduced. The circuits were secured by iron staples usually without moulding.

A further step in the line of progress was made by using a tinned conductor wrapped with cotton thread, then a preparation of rubber with paraffined cotton braiding, the whole being protected by a lead sheathing. Fibre staples were used, a special tool being required to set them in place. Salt water found its way into these conductors where they passed through decks and bulkheads, whereas sections over boilers were thoroughly baked, resulting in disintegration of the insulating material and grounding of the lead covering. Specifications for the next installations required copper to be tinned, insulated by cotton wrapping, a layer of white rubber, and then the lead sheathing as before. Previous experience has shown the larger size conductors to lack flexibility and to tend toward rupturing the lead sheathing at bends, and accordingly stranded conductors for the larger circuits came into vogue.

This wire was further improved by interposing a layer of pure Para rubber between the cotton wrapping and the vulcanized rubber. For this style of wire an insulation resistance of 1,000 megohms per mile was specified for a sample 500 feet long, after immersion in sea water for 24 hours.

The next step in the evolution of wire for ships' use consisted in coating the conductor with a heavy layer of cotton braid saturated with insulating compounds, which covering replaced the lead sheathing, the rubber coverings being relied upon to exclude moisture. This latter wire gave satisfaction and frequently outlasted the mouldings in which it was installed. The wire in present use conforms to the following requirements: All conductors to be of soft annealed pure copper wire. When greater conducting area than that of 14 B. & S. G. is required. the conductor shall be stranded in a series of 7, 19, 37, 61, 91 or 127 wires, as may be required; the strand consisting of one central wire, the remainder laid around it concentrically, each layer to be twisted in the opposite direction from the preceding, and all single wires forming the strand must be of the diameter given in the American wire gauge table as adopted by the AMERICAN INSTITUTE OF ELECLRICAL ENGINEERS, October, 1893.

The material andmanufacture of the strand must be such that the measured conductivity of each single wire forming the strand shall not be less than 98% of that of pure copper of the same number of circular mils, the measured conductivity of the conductor as a whole to be not less than 95% of that of pure copper of the same number of circular mils; each wire to be thoroughly and evenly tinned; all single lighting conductors shall be insulated as follows:

First. A layer of pure Para rubber, not less than 1/64" in thickness, taped or rolled on; if taped, the tape to lap one-half of its width.

Second: A layer of vulcanized rubber about 3/32" thick.

Third: A layer of commercial cotton tape, lapped to about 1/32" in thickness.

Fourth: A close braid to be made of No. 20 2-ply cotton thread, braided with three ends for all conductors under 60,000 c.m., and of No. 16 3-ply cotton thread, braided with four ends for all conductors of and above 60,000 c.m. The outside diameter over the braid to be in exact conformity with that tabulated.

TESTS.

The sample, after 24 hours immersion in sea water, must have an insulation resistance of not less than 1,000 megohms per nautical mile.

The test is to be at 72° F.

The sample is to be tested by the direct deflection method at a potential of not less than 200 volts.

Sample will be tested for a conductivity of not less than 95% of that of pure copper, having a cross-section of the specified number of circular mils.

Chemical tests will be made to determine the constituents of the different layers of the insulation.

Braid will be tested for waterproof qualities.

Physical tests will be first made for qualities of strength, toughness, dimensions, etc.

The physical and electrical characteristics of the insulation under change of temperature will be tested by exposing the finished conductor for several hours at a time, alternately, to a temperature of 200° F. (dry heat), and the temperature of the atmosphere, during a period of three days.

The tests for characteristics of the insulation will then be repeated, and must show no practical deterioration on the results of the former test.

All twin lighting conductors shall consist of two conductors, each one of which shall be insulated as follows:

First: A layer of pure Para rubber, not less than 1/64″ in thickness, taped or rolled on.

Second: A layer of vulcanized rubber about 1/16″ thick.

Third: A layer of commercial cotton tape, lapped to about 1/32″ in thickness.

Two such insulated conductors shall be laid together, the interstices being filled with jute, and covered with two layers of close braid.

Each braid is to be made of No. 20 2-ply cotton thread, braided with three ends.

The copper wire and tests of finished are conductor to be as specified for single conductor.

MOTORS.

Motor applications on board ships involve the use of all sizes of motors from 1/12 h. p. to 50 h. p. Fans for officers' quarters are of two sizes, 1/12 h. p. and 1/6 h. p., the former for 12-inch desk or bracket fans, the latter for 16-inch bracket fans. Small

$\frac{1}{4}$ h. p. series motors are used on portable ventilating sets. These sets are necessary for temporary ventilation when working in such parts of the ship as are not reached by the main ventilating system.

The main ventilating system employs motors of all sizes from $\frac{3}{4}$ h. p., used with small exhausters, up to 15 h. p., which are used on the larger steel plate blowers. The controlling panels for these motors contain a double-pole line switch and a rheostatic starting-box with an automatic no-voltage and over-load release. A field rheostat for speed control is also mounted on the panel.

Ammunition hoists for 5-inch and 6-inch, and smaller guns, are either endless chain hoists or whip hoists, and are operated by shunt-wound reversible motors. A motor of about 3 h. p. is used for the endless chain hoist and motors as large as 6 h. p. are used on the whip hoists. The chain hoist motors as a rule are located below the protective deck. They drive through gearing and are controlled by a panel similar to those described for the blower motors, and in addition by a double-pole, double-throw reversing switch. These motors are fitted with solenoid brakes, which release when the lever is moved to first notch and set up when the lever is thrown to off position. Motors for whip hoists when located in exposed places on the decks or bridges, are made water-tight by means of iron plates over the hand holes set up against sheet-rubber gaskets. They are fed from the line through branch blocks and switches enclosed in water-tight boxes. An enclosed cylindrical reversible controller is used.

For turret guns chain hoists are also used, the motors being either suspended under the base of the turret or in the turret itself. These motors as a rule drive through a flexible cable, running over a drum on an intermediate shaft. Motors as large as 30 h. p. are required for the 12-inch mounts, motors of about 16 h. p. for the 10-inch mounts and 8 h. p. motors for the 8-inch mounts. The first two run at 350 r.p.m., the last at 400 r.p.m. Each gun in a turret has its own ammunition hoist motor. The controllers are operated by a single handle, capable of sudden reversal, and carry the load in either direction without change of speed. Automatic circuit-breakers are installed which break armature current only. The guns are elevated and depressed by shunt-wound motors of about 5 h. p. capacity, controlled in a manner similar to the ammunition hoist motors. For forcing the shell into the breech of the guns, rammer motors are used.

These motors are series-wound, and drive through a friction sheave so adjusted that in case the shell is set home before the motor is stopped, the slipping of the driving mechanism will hold the motor load down low enough to prevent the throwing of the circuit-breaker. These motors run at about 750 r.p.m., and are of 7 h. p. output for 12-inch mounts and 5 h. p. for 10-inch mounts. They carry the load in one direction only. Small motors are used to furnish air blast for clearing smoke out of the guns after firing.

Turrets are turned by motors operated on the Ward Leonard system, as at present installed, the use of a separate generating set being required for turning each turret. A system now under consideration embodies the use of a motor-generator for each turret, several of such motor-generators being supplied by one generating set. For 12-inch turrets, two 35 h. p. motors are installed, either one being capable of handling the turret alone. These motors, located diametrically opposite each other, drive a common cross-shaft through bevel gears, this shaft carrying near each end a separate worm, which actuates a pinion on a vertical shaft. The lower end of the vertical shaft carries a gear which meshes with an annular gear attached to the inner side of the barbette. The controller, located just under the sighting hood, is operated by one handle, and carries the load equally well in either direction. Automatic cut-outs are fitted at the limits of travel of the turrets.

Recent tests on turrets fitted as above show a nicety of control which is all that could be required. The turret was moved ten successive times, and only turned through an arc of 30.9 seconds. This would mean a single movement of 3.09 seconds, a distance scarcely discernible on the circumference of a 14-foot circle (the outside of the turret). The turret was turned throughout its range of travel, 136° starboard to 136° port, a total of 272° in less than 45 seconds. The weight of the mass moved was about 600 tons.

Boat-cranes as at present installed have but one motor for both hoisting load and revolving cranes, although on ships now under construction, separate motors will be used for each purpose. About 50 h. p. will be used on the larger cranes for hoisting and lowering, and about 25 h. p. for revolving the crane. The control of the hoisting motor is by means of a resistance continuously across the line, the speed being controlled by the amount of the resistance with which the armature is placed in shunt. With this system, should the load on the crane tend to drive the armature at a speed in excess of that corresponding to the position of the controller handle, the armature will drive a current through the local circuit and run at constant speed unitl shut down.

In addition to the above-mentioned uses, motors are used to drive air compressors for use in torpedo work, such compressors requiring about 25 h. p., for closing water-tight doors; for lifting hatches; for dough mixers; for driving machine tools in the ships' workshops; for laundry work, etc. Electrically-operated steering gear and electrically-driven pumps are not used in our navy, although some foreign powers have applied the electric drive to such auxiliaries.

Interior and Exterior Signaling.

The means of interior communication consist of voice tubes, electric call-bells and annunciators, telephones, fire-alarms, general alarms, warning signal, engine telegraph, steering telegraph, helm indicator, revolution and direction indicator, battle and range-order indicators and transmitters. When a limited number of orders are to be transmitted, the telegraph is used; when an unlimited number of orders are to be transmitted and interior communication is necessary, telephones or voice pipes are installed, telephones being used for the longest leads. Between important stations, both telephones and voice pipes are installed. Call-bells and buzzers are used without returns for minor purposes.

The fire-alarm system comprises an annunciator, near the captain's cabin (under the eye of the cabin orderly) and thermostats located in coal bunkers, magazines and storerooms near the same. When the temperature in these places rises above 200° F., the alarm is given at the annunciator and the location is indicated. The thermostat in present use, Fig. 8, consists essentially of a helix of metal ribbon (metal having a large expansive co-efficient) and a terminal block, with an adjustable contact screw. Its operation is based on torsional strain produced in the helix by a rise in temperature, thus completing the circuit through the contact screw in the terminal block. The spiral embraces the shank of a " T "-shaped casting, the lower end of the spiral being connected to the lower end of the shank. The top of the spiral ends in a flat piece which extends across the top of the casting. One arm of the " T " is extended and is provided with a screw terminal for attaching live wire. The spiral terminal is secured to an insulating plate of mica, Fig. 2, provided with a large hole in the center, through which the spiral is thrust, and other smaller holes by which it is secured to the spiral terminal, the other terminal and the bottom of the box.

The adjustable contact, Fig. 3, is a brass casting with an adjusting screw *a*, a screw terminal *b* for attaching the live wire, and two screws with washers *c* and *c* for securing the mica plate. A water-tight tube, Fig. 5, passes through a hole in the casting, Fig. 6, which forms the lower side of the conduit box, Fig. 7.

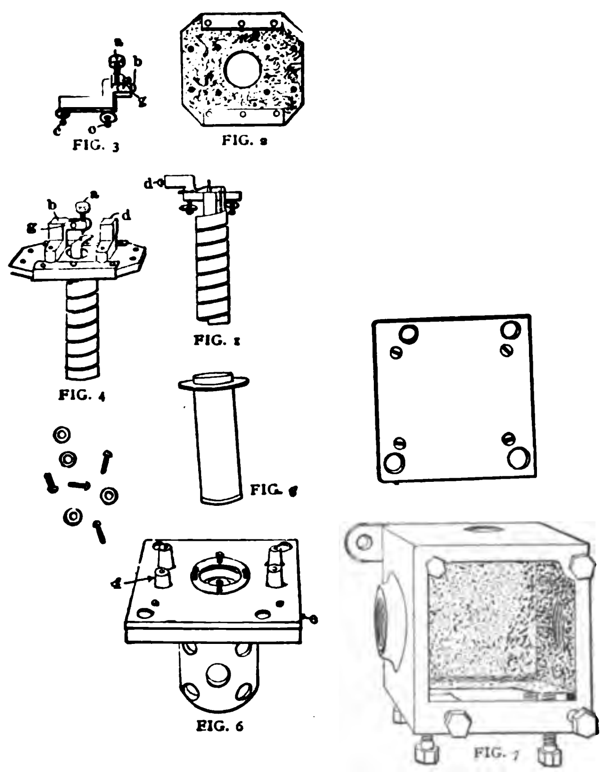


FIG. 8.—Conduit Thermostat, Type "A."

The top of the tube is flanged and is made water-tight by the rubber gasket *e*, Fig. 6, being secured by four screws. The mica plate with the spiral and terminals assembled thereon is fastened by four screws with washers to four studs *f*, Fig. 6, the spiral extending down into the water-tight tube.

To adjust, the working parts are taken from the box, Fig. 7, so as to be readily assembled. The proper electrical connections having been made (bell and battery in series with *b* and *d*

Fig. 4), the water-tight tube, Fig. 5, containing the spiral, is placed in water as deep as possible, without allowing the water to run over the top of the tube. The water is then heated and the rise of temperature is as follows:

80° to 100° F. 5 minutes.
100° to 110° F. 10 "

When the temperature has reached the latter limit, the adjusting screw is run down until the circuit is closed and the bell rings. The fixture is made heavy with strong gear to resist mechanical injury.

General Alarm System.—This consists of a board on which is mounted a 12-inch gong and a brass case containing clockwork. The case contains a heavy coil spring which will give the alarm twice. The drum of the spring is connected by a gear wheel to a spindle carrying upon its outer end a star-wheel with an anti-friction roller at the end of each star. These projections of the star-wheel take against the face of a lug attached to the lower end of the bell-clapper, and as the star wheel revolves counter clockwise, it raises the clapper until the friction roller releases the lug, which allows the clapper to fall by its own weight and by the aid of a spring. Two electro-magnets with double armatures, one carrying a pin, control the release of the main spring. A train of gear wheels are connected to the main spring drive, controlling the speed of unwinding the spring. Connected with the gear wheel is an escapement disk with holes in the surface for the pin of an armature arm. The pin on the armature is controlled by a double armature designed to prevent the release of the pin by the shock of gun fire, or otherwise.

The action of the mechanism is as follows: The electro-magnets with connections to line attract the horizontal and vertical armatures when the circuit is closed. The top of the horizontal armature takes under the adjusting screw on the end of a vertical armature and thus prevents the vertical armature from moving toward the magnets until the top of the horizontal magnet is driven in to clear the screw. When the vertical armature is attracted to the magnets, the pin taking the escapement disk is driven clear. Through the train of gear wheels, the main spring is then released and continues to revolve the star wheel, sounding the alarm for thirty seconds, or until the pin again falls into a slot in the escapement disk.

The contact-makers are usually located in the conning tower or the captain's stateroom, and from these points the entire system of gongs may be put in operation. The contact-maker consists in general of a water-tight box containing a hard-rubber base upon which are secured six contact sections, separated from each other. A spider carrying switch lever is also secured to the hard rubber base on the under side. A metal spring on the spindle of the switch keeps it away from the contact sections and thus leaves the circuit open. The gongs are on battery circuits in multiple.

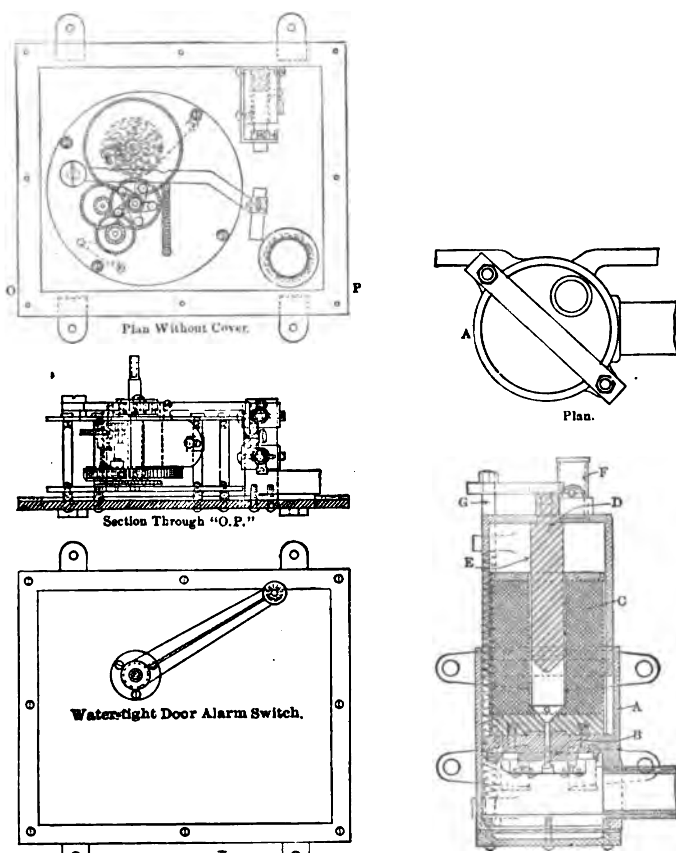


Fig. 9.

Solenoid Whistle.—These whistles, one of which is shown in Fig. 9, are used as a signal for closing water-tight doors, and consist of a contact-maker, which is usually placed in the pilot house, and solenoid whistles located throughout the ship. The whistle consists of a brass case, A, forming the chamber for wire terminals, space for the conduit terminal, outer cylinder of apparatus and lugs for securing the whole to the bulkhead. An insulated base, B, secured to the brass case carries a coil, C, incased in a brass cylinder, with hollow center about 1 inch in diameter. The plunger coil, D, forming an air chamber above the solenoid, is of iron, being an inverted hollow cylinder fitting closely over the outside of the coil and inside the brass case A. It is closed at the top and carries the armature plunger, E, of iron projecting downward into the solenoid. A shrill whistle, F, is mounted on this plunger case over a hole through the top of the cover. Two rods, G, fastened to lugs on the base of the brass coil carry spiral springs fitted between the lugs on the plunger cylinder and the lugs in the base, forcing the plunger up until it takes against a bridge on the top of the rods. This is the normal position of the plunger cylinder. Each wire terminal is fused on a porcelain base with a fuse of 3 amperes capacity.

The action of the whistle is as follows: When the circuit is closed by the contact-maker in the pilot-house, the current flows through the coil of the solenoid, exerting a strong pull downward on the plunger E, and drawing the plunger cylinder D downward against the force of the springs. There being no escape for the air in the air chamber of the cylinder, except through the whistle, it gives a shrill sound. When the circuit is broken by the contact-maker in the pilot-house, the coil no longer exerts a pull on the armature, and the two spiral springs force the plunger cylinder back to its upper position at the time the contact-maker again closes the circuit, and the whistle is made to sound again as before, this action lasting for about 35 seconds, giving a succession of shrill, sharp whistles.

The electrical engine-telegraphs located in the pilot-house and conning tower are only used to signal an increased or decreased number of revolutions, and are chiefly used in steaming in squadron, the range of signals being sufficient to preserve formation. The speed designated by the flag officer is telegraphed by means of the ordinary mechanical telegraph and small variations from the speed, by the electrical devices. The transmitter includes an indicator and consists of a pedestal with a cylindrical case mounted thereon, containing the mechanism for ringing a magneto-bell at the indicator station and making an electric light burn behind a figure on the dial of the indicator. [See Figs. 10 and 11.] The form of a transmitter and its operating handles and clutch resemble the mechanical engine-room telegraph. On the spindle of the operating handle is a metal wheel

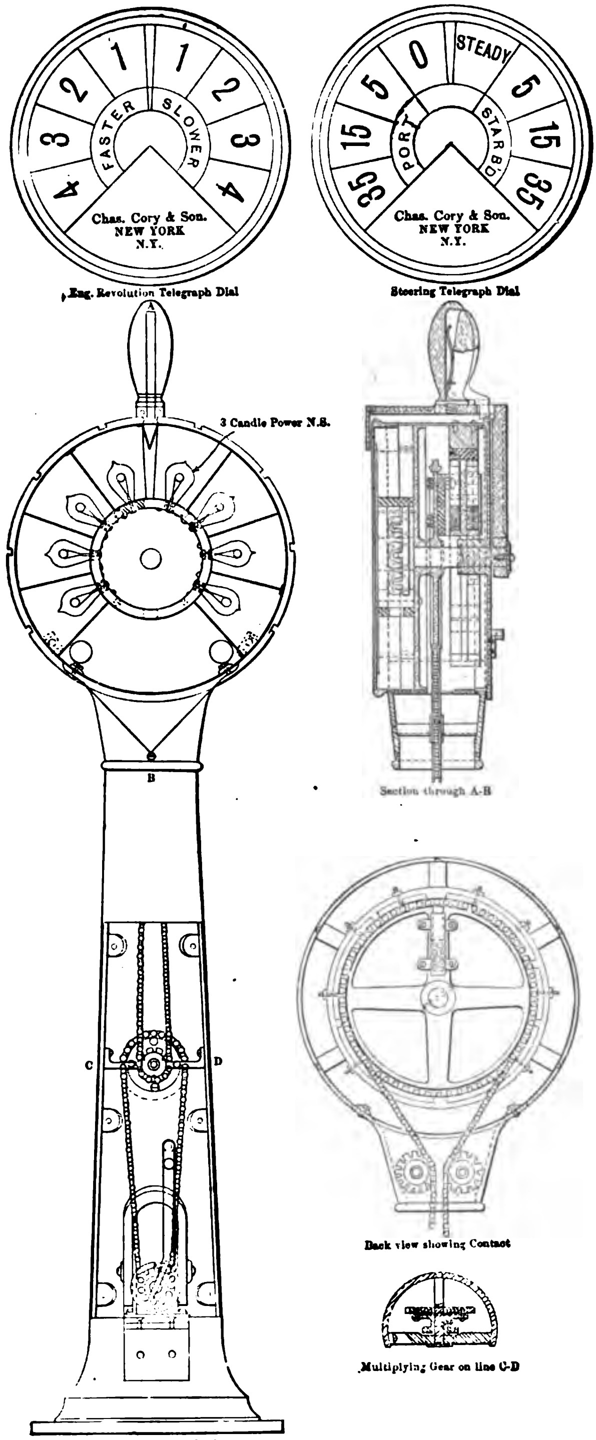

FASTER
SLOWER
Chas. Cory & Son.
NEW YORK
N.Y.
Eng. Revolution Telegraph Dial
STEADY
PORT
STAR B'D
Chas. Cory & Son.
NEW YORK
N.Y.
Steering Telegraph Dial
A
3 Candle Power N.S.
B
C
D
Section through A-B
Back view showing Contact
Multiplying Gear on line C-D
Front view showing Indicators

FIG. 10.

geared to fit on a sprocket chain. This chain leads down into a pedestal to a multiplying gear, and thence another sprocket chain leads to an armature of a magneto-generator secured in the pedestal. Wires are led from the brushes of this magneto-generator to the magneto-bell in the engine-room. Fastened to the sprocket-wheel of the transmitter on the after side is a contact-maker insulated from the wheel. It carries a pair of carbons, each pressed outward by a spring in the base. The

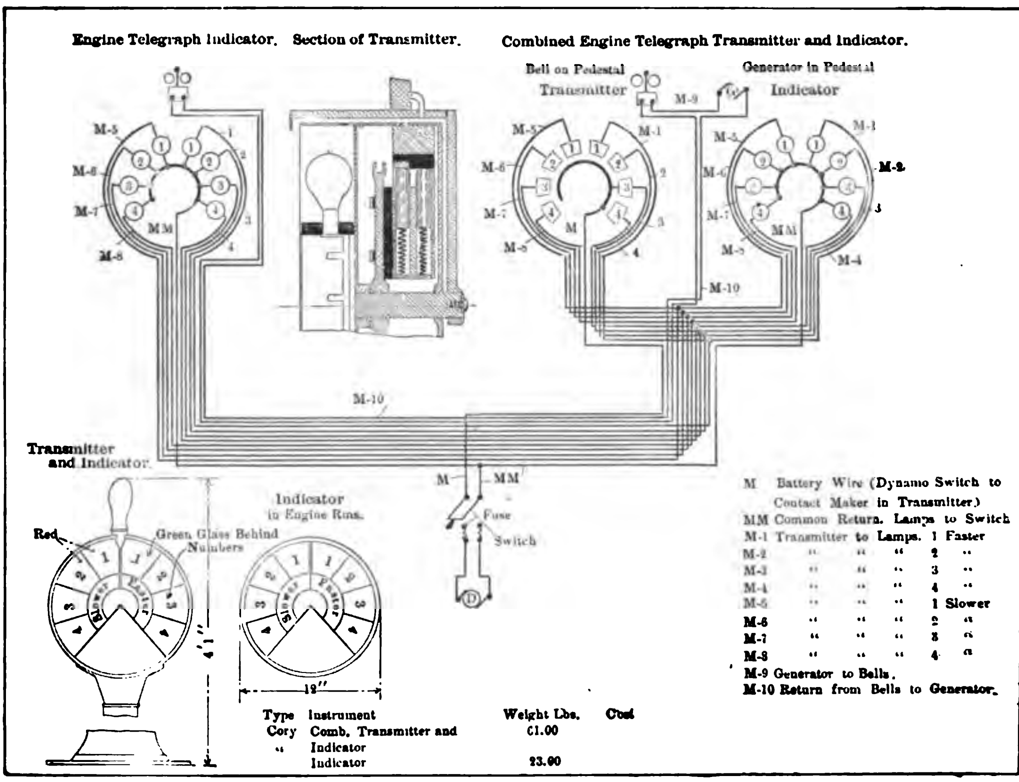


FIG. 11.—Electric Engine Telegraph.

carbons make contact with metal sections secured to a circular hard-rubber base on the frame of the transmitter. One of these sections, connected to a common return wire, extends around the face of the instrument and is always in contact with the contact nearest the fuse. The other carbon makes contact with separate strips of metal, one for each order on the transmitter, which metal strips are connected with the section wires leading to the indicator and are insulated from each other. The path of the current through the contact-maker when the pointer of the operating handle is over an order on the dial, is from the section wire contact into one carbon, through the metal socket, through the other carbon into the common return contact and out again to the line. A green glass is behind the numbers on the left side, which indicate slower speed. Sockets for the lamps are fitted to a hard-rubber base, and the connections to the wire are made in the center. Each lamp is connected to a common return and to that section wire which connects with a compounding contact in the transmitter. Each lamp is in a separate compartment, so that it can illuminate only one of the perforated numbers. The indicator in the engine-room is similar to the transmitter in all respects, with a magneto-bell placed above it. The figure shows the scheme of wiring, the current being taken directly from the main switchboard at normal potential. The magneto-bell on the indicator in each engine-room is wired in series with the transmitter in the conning tower and the pilot-house. A special arrangement is necessary on the transfer switch in the conning tower to bridge over the bell-circuits and not open the circuit. There is a transfer switch in the conning tower to cut out the pilot-house instruments when using those in conning tower.

Steering Telegraphs.—These are used to signal the desired degree of helm from the conning tower and the pilot-house to all steering stations. Combined transmitters and indicators are located in the conning tower and the pilot-house. Indicators are placed in the communication room, hand-steering stations on the upper decks and steering engine-rooms. These devices are exactly similar to the engine-telegraphs described above, except the orders on the dial.

Helm-angle Indicators.—These instruments, shown in Figs. 12 and 13, are installed at all steering stations, and indicate simultaneously the rudder angle at these stations. They are similar to the engine telegraphs, except the marking on the dials. The transmitter is located in the tiller room, the contact-maker, or arc, being secured on the rudder-head. The transmitter consists of a base of vulcanized rubber in the form of an arc, fastened to an iron bracket, carried on one of the protective deck beams Upon the base are fastened fifteen strips of brass of varying widths, the center line of the strips being at angles, 0°, 2½°, 5°, 7½°, 10°, 15°, 25° and 35°, with the center line of the ship. These straps are insulated from each other by narrow sections of slate, the whole forming an arc of 60°. On the inner side of this line of fifteen contacts and close to it, is a continuous strip of brass extending over the same length of arc. The contact-maker con- the section straps and the common return strap by spiral springs

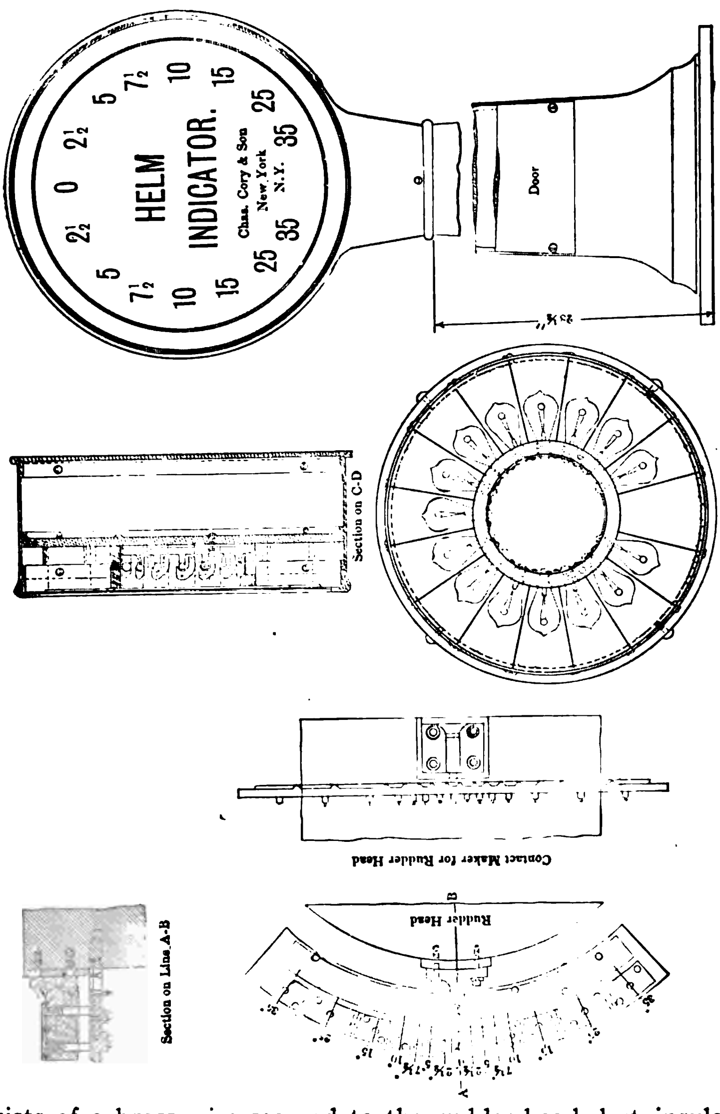


FIG. 12.

sists of a brass wire secured to the rudder-head, but insulated from it by hard rubber. Two holes bored in the ends of the arm carry the carbon contacts. These are forced downward against above the carbon, completing the circuit between the common return and the section straps. Each section strap is connected to the lamp in each indicator, corresponding with the angle at which the section strap is placed. Then, if the rudder is hard to port, the helm hard to starboard and the connection is made between the common return strap and the section strap through the carbons, the light in all indicators will burn 35° to starboard.

Revolution and Direction Indicators.—These indicators, shown in Figs. 14 and 15, are located in the pilot-house and con-

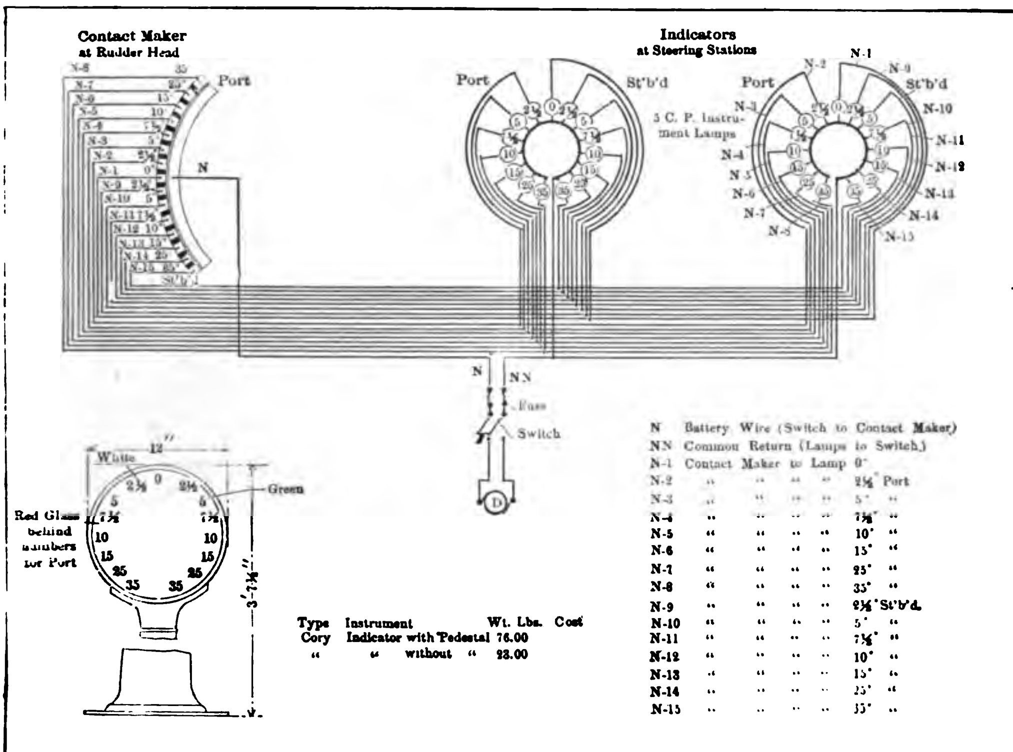


FIG. 13.—Helm Angle Indicator.

ning tower, one for each engine. The indicator consists of a circular water-tight case with glass face. The enamel dial is marked " ahead " and " astern " just over two small pointers. [Fig. 1.] Two sets of double-pole electro-magnets, A [Fig. 2], are mounted on the back of the case, one set for ahead and one set for astern. The figure shows the upper magnets only. Each set of magnets has an armature, B, pivoted on a vertical lug at the side of the coil, C. The end of the armature takes against the side of a vertical spindle, D, which carries a pointer at the end. A score, or flat recess, is cut in the round spindle where the armature bears against it, which score lies against, and at an angle of 45° to the armature. When the armature is attracted to the magnets the end is driven against the spindle and turns it until the screw is flat against the armature, thus turning the spindle and the pointer at its end through an angle of 45°. When the circuit in the electro-magnet is broken, the magnets cease to attract the armature, and a spiral spring at the base of the pointer-spindle levels the spindle back to its normal position and the score again lies at 45° to the armature. The circuit is made and broken at each revolution of the shaft, and it depends upon the direction of the revolution of the shaft as to which set of magnets is energized. A switch is placed at the bottom of the indicator, and a spiral spring in the base to bring it back to mid-position when twisted to the right, and to close the circuit.

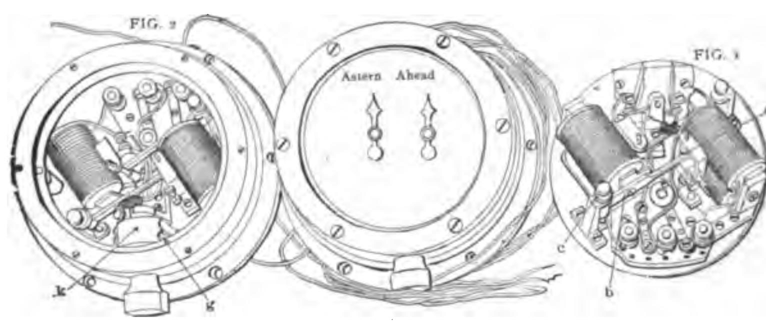


FIG. 14.

Two upright contact-strips of metal, G [Fig. 2], on each side, bear against a hard-rubber ring, K. Inserted longitudinally in this hard-rubber ring are two pieces of metal, which make connections with the upright strips, G, on both sides when the switch is twisted. This switch is in circuit with the common return of both sets of magnet wires, as shown in the diagram of connections [Fig. 5]. A lamp is installed in the indicator and illuminates the dial.

The contact-makers on the main shaft shown in Fig. 15, are located in the shaft alleys. An iron bracket in the bulkhead supports a hard-rubber base, A [Fig. 3]. A vertical sliding rod, B, is attached to the base and is in electrical connection with one wire of the common return. On the lower end of the sliding rod, a small gear wheel, C, is carried, gearing into a band, D, [Fig. 4], which is secured on the main shaft, being eccentric to the shaft

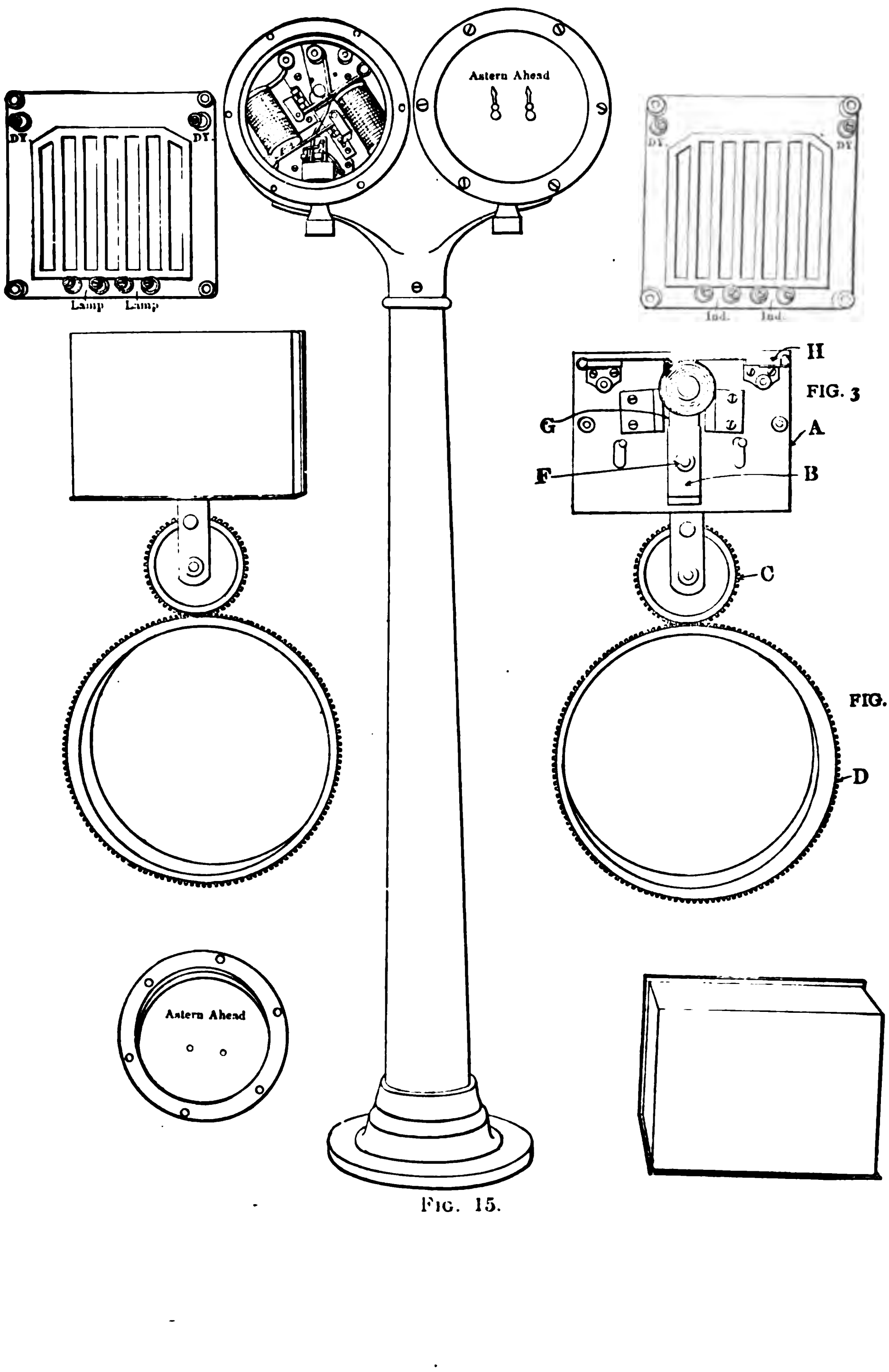

DY.
DY.
Lamp
Lamp
Astern Ahead
DY.
DY.
Ind.
Ind.
H
FIG. 3
G
A
F
B
C
FIG. 4
D
Astern Ahead

FIG. 15.

and having three-quarters of an inch throw. The teeth of this eccentric band are cut to fit those on the pinion on the sliding rod. When the shaft revolves a vertical sliding motion is imparted to the rod which is raised and lowered three-quarters of an inch at each revolution. A special spring is installed to keep the pinion in contact with the band. The rod is pivoted in about the center, F, the pivot pin working in a slot in the rod and the top being free to oscillate. When the shaft is turning ahead, the upper end of the rod is thrown inboard and takes against two small rollers, G, mounted on the base, avoiding friction as the rod is raised and lowered. One section wire leading to "ahead" magnets of the indicator is connected to a spring, H, mounted on a hard-rubber base above the sliding rod; the section wire leading to the "astern" magnets is attached to a similar spring on the opposite side. When the shaft is turning ahead, the connection between the end of the sliding rod and the section wire of the "ahead" magnet is alternately made and broken, and the indicators in the conning tower and pilot-house will show a deflection of the pointer for each revolution. When the shaft is turning astern, the connection is made and broken between the rod and the section wire leading to the "astern" magnet in the indicator.

Battle and Range Order Telegraphs and Indicators. These instruments, illustrated in Fig. 16, are used to signal the orders to the battery, ammunition supply and the range. The principle of the battle-order and range-order instruments is that each order on the indicator is shown by a separate 5 c.p. lamp, controlled by a separate switch on the transmitter. The orders are marked on the counter by transparent plates on the face of the indicators, each plate having a lamp behind it in a separate compartment. The orders on the indicators are only shown when the lamp behind the order is made to burn by turning the switch of the transmitter. Any number of orders may be shown at the same time. The instruments are wired in parallel and when a switch of the transmitter is turned, the corresponding order is shown on all the indicators. Fig. 16 shows the general design of these appliances. The orders signalled are, commence or cease firing, character of projectile to be employed, full or reduced charge, direction of the enemy and distance in yards.

ARDOIS SIGNALLING SYSTEM.

The object of the night signaling set, shown in Figs. 17 and 18, is to transmit rapidly and accurately under suitable condi-

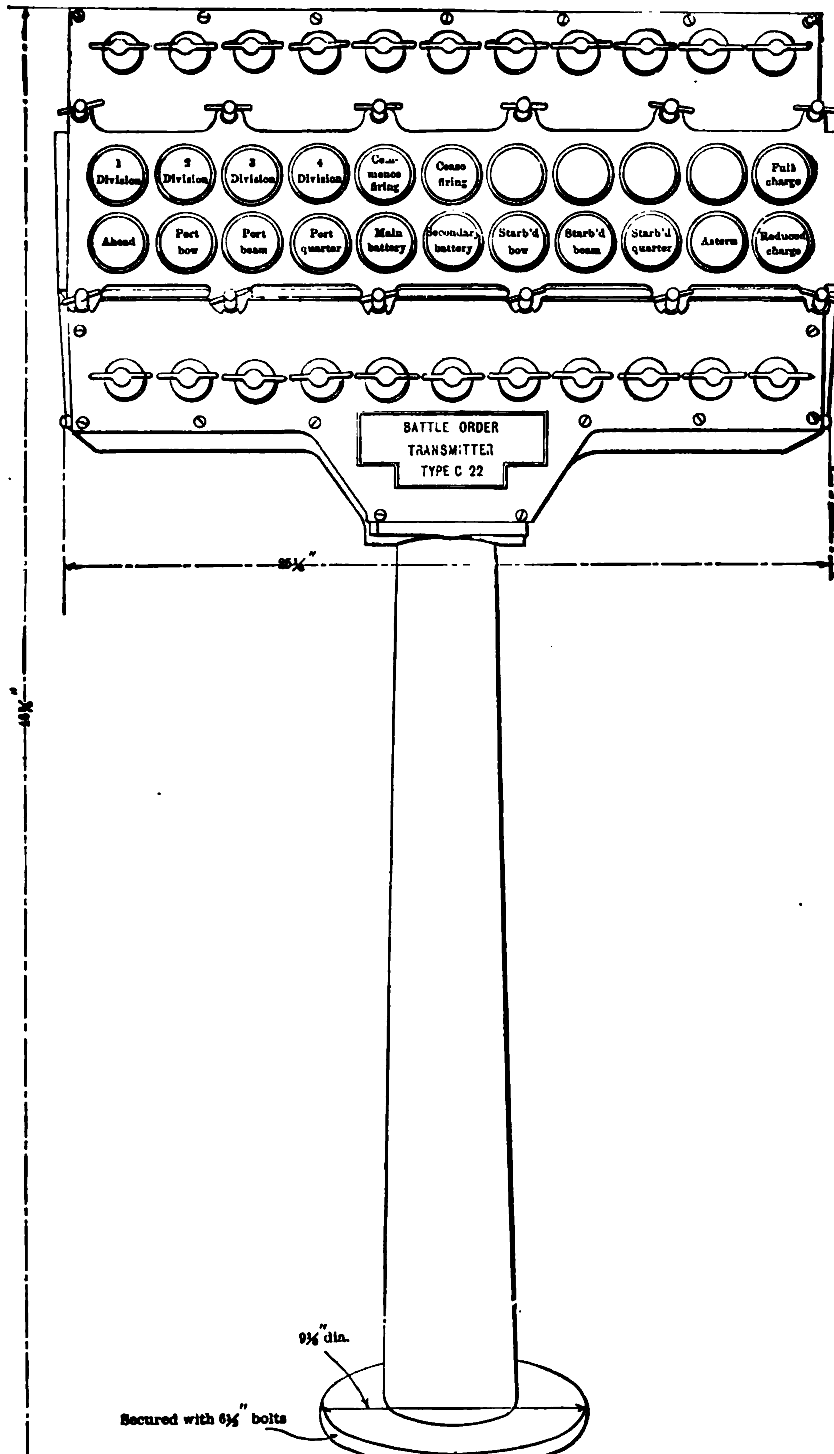


FIG. 16.—Battle Order Transmitter.

tions, a pre-arranged code of signals to a distant point, as from one vessel to another, or for squadron and fleet tactics, and for signals between vessels and co-operating commands on shore. The method is as follows: With current on the circuit, by oper-

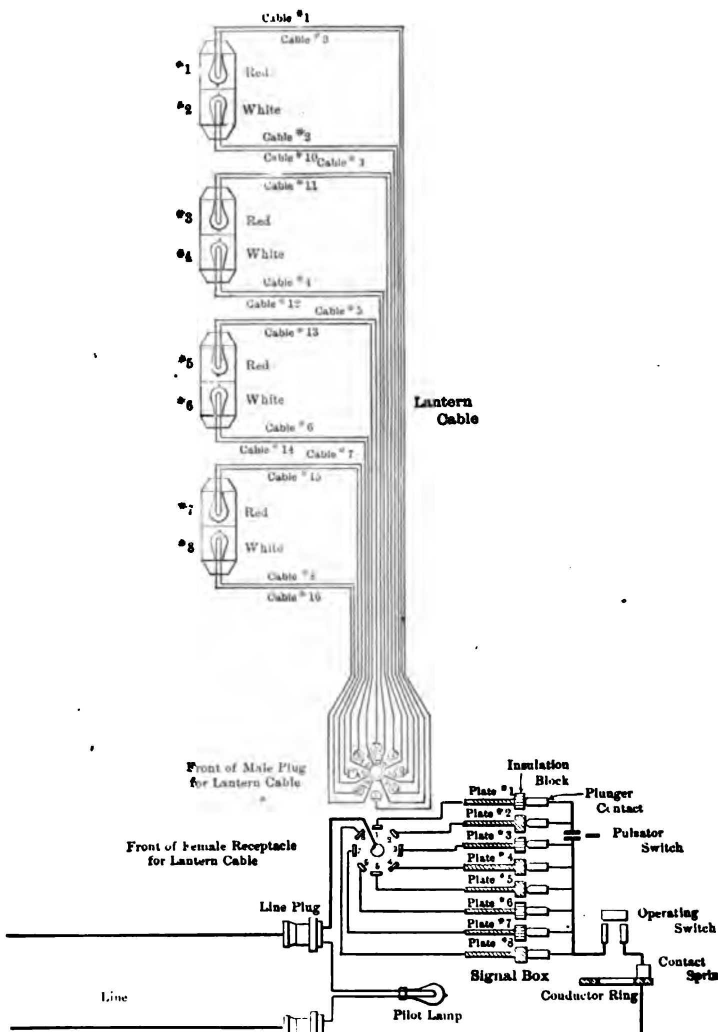


FIG. 17.—Hand Control Projectors.

ating the handle of the switch lock on the keyboard, the various combinations represented by dots on the dial plate in Fig. 19, are made to appear by the illumination of lamps in the lanterns, and by working the handle of the pulsating switch on top of the spindle, the lights in the upper lantern are pulsated. The set consists of four double lanterns with lamps, a ladder, cable and keyboard. Each of the four lanterns shown in Fig. 18 has two compartments; the upper one has a red lens, the lower one a

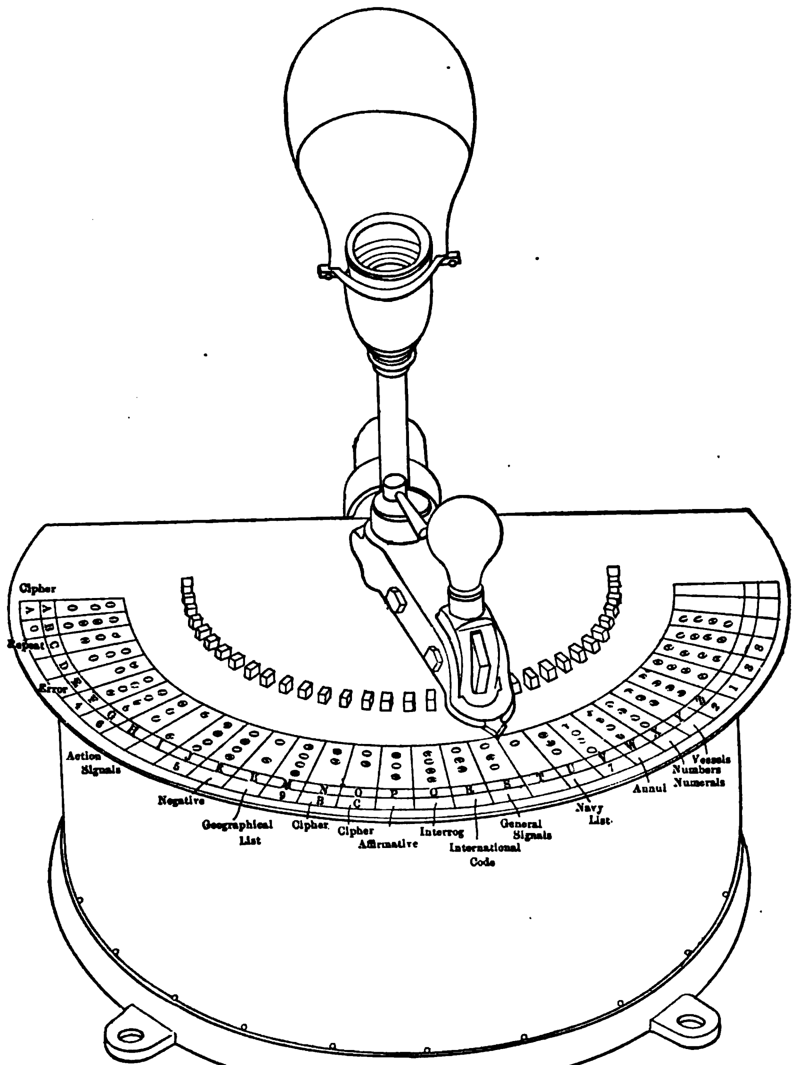


FIG. 18.—Connections for Signal Set Form "E."

white lens. The wires from the cable pass through stuffing boxes in the center of the caps, which screw on each end of the lantern and make it watertight by a gasket. Each cap is fitted with a socket and a standard 32 c.p. lamp. The ladder is made of galvanized iron wire. One end of the ladder is made fast to an outrigger, or short gaff, near the masthead and the other end is secured to a turnbuckle fastened to the deck. The cable consists of 16 conductors, each lamp having its own return wire. The wires connect to a plug which fits into a receptacle on the keyboard. The keyboard consists of a dial, handle for the pulsating switch, and the operating handle mounted on a water-tight box. It is illumined by a standard 32 c.p. lamp, supplied with a shade. The water-tight box contains the mechanism for connecting the lamps in the various combinations and con-

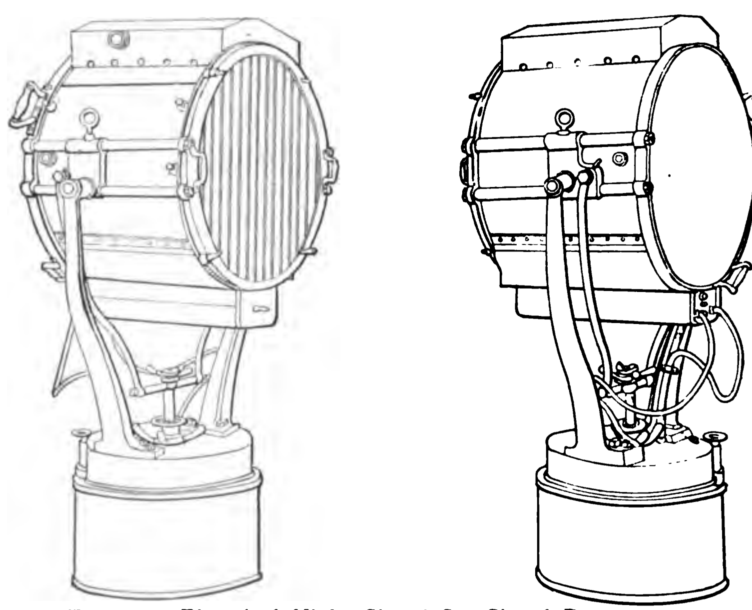


FIG. 19.—Electrical Night Signal Set Signal Box.

sists of a rotating stud provided with eight spring-contact plungers, which rest against eight semi-circular plates. These plates are made up of insulating sections of hard rubber and composition, each of which is in connection with its respective lamp. When one of the contact fingers of the rotating stud rests on an insulating section, the circuit through the lamp is broken, but when it rests on a metal section, the circuit is closed. When the pointer is turned to the position on the dial corresponding with the desired signal, some contact plungers rest on the hard-rubber section and others on the metal section, thus connecting into circuit the desired combination of lamps.

SEARCHLIGHTS.

Searchlights, Fig. 19, consist of a fixed pedestal, or base, surmounted by a turntable, carrying the drum in which are contained the lamp and the mirror. The base contains the electric connections and is arranged for bolting direct to the deck and platform. The turntable is free to revolve indefinitely in either direction in a horizontal plane, and may be clamped rigidly in any position, Fig. 20. The drum is trunnioned on two arms bolted to the turntable, and has a vertical train of 70° above horizontal and 30° below. This drum may likewise be clamped in any intermediate position. Parabolic mirrors are now used and are of highly polished glass,

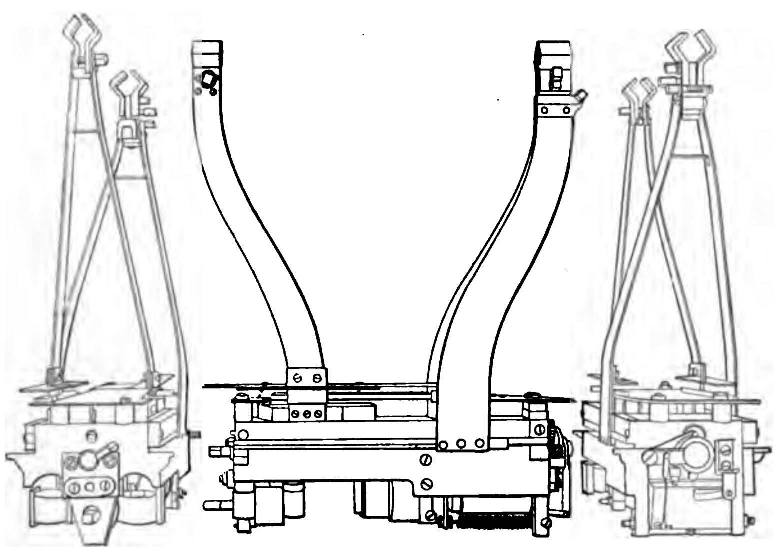


FIG. 20.

silvered on the back. The mirror is mounted in a separate metal frame, lined with non-conducting material in such a manner as to allow for expansion due to heat, and to prevent injury from concussion. The lamp is of the horizontal carbon type, designed for both hand and automatic control. It will burn for six hours without renewing carbons. The front of the drum contains a door of plain glass strips and a shutter for use in signalling. Until recently, the projectors were fitted with a system of electrical control for training the beam of light, but at present hand control is exclusively installed. The intensity of the beam of light is required to be such that on a clear, dark night a light-colored object 10 by 20 feet in size will be plainly discernible at a distance of not less than 4,000 yards for the 18-inch projector, 5,000 yards for the 24-inch projector and 6,000 yards for the 30-inch projector. The current required for operation with the voltage across the arc for the four standard sizes is:

13-inch,	18–20 amperes,	45–48 volts.
18 "	30–35 "	47–50 "
24 "	40–50 "	48–52 "
30 "	70–80 "	49–53 "

Smeltzer carbons are used extensively and give good satisfaction, the positive carbon in the larger sizes being corded, with the negative carbon solid and in some cases having a core smaller than that of the positive carbon.

INCANDESCENT LAMPS.

Under the old practice, incandescent lamps were not only of a special voltage, but of a special type of bulb, and delay was experienced in supplying the service with the number required. Under the new voltage recently adopted, 125 volts at machine terminals, the lamp will be of 123 volts, with an allowed variation from 122 to 124 volts for the 16 c.p. lamps, and from 121 to 125 volts for the submarine, or diving lamps. The 16 c.p. lamp, the one most used, will conform in shape with the commercial type, and thus enable its purchase in the market as a common commercial article. It will be seen that the voltage of the lamp and the variation in voltage allowed, from 122 to 124 volts, is consistent with the maximum allowed drop on the lighting circuits, and will admit of the installation of lamps at the voltage at which they deliver their rated candle power. The following are the standard lamps allowed: 16 c.p., clear and frosted; 32 c.p. clear, and 150 c.p. clear, in the case of the diving lamp, besides instrument lamps for special purposes of 1 and 5 c.p. The average efficiency of the 16 c.p. lamp is to be between 3.4 and 3.6 watts per candle power; for the 32 c.p. between 3.4 and 3.8 watts per candle, and for the 150 c.p. diving lamp between 2.9 and 3.3 watts per candle power. The life of an incandescent lamp is an important consideration in naval installation, as the ships are so frequently removed from a source of supply. It is proposed to specify 800 hours for the 16 c.p., 500 hours for the 32 c.p., and 300 hours for the 150 c.p. lamp as the average life, with the above efficiencies, the lamps not to have lost more than 20% of their rated candle power while burning for these periods at the rated candle power.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

THE MILITARY CABLE SYSTEM OF THE PHILIPPINES.

BY CAPT. EDGAR RUSSEL, SIGNAL CORPS, U. S. ARMY.

After the progress of negotiations of the Commission at Paris in November, 1898, had made it certain that the retention of the Philippines would be recommended, steps were immediately taken by Gen. A. W. Greeley, the Chief Signal Officer of the army to provide for the inter-island communication which his forecast of coming conditions indicated would be necessary. With this in view, arrangements were made for the purchase of cable and the fitting out of a suitable ship for cable laying.

It should be stated that at this time there were no government cables in the Philippine archipelago, and but one commercial cable system, about 600 miles long, that of the Eastern Extension Telegraph Company, which connected Manila,Luzon, with Iloilo, Panay; Bacalod, Negros; and Cebu, Cebu. There were no Spanish land lines except on the island of Luzon, and these falling into the hands of the insurgents in a deteriorated condition, went to pieces and required replacement by the Signal Corps. It may thus be said that no telegraph system existed in the islands, apart from the single commercial cable system mentioned above.

As soon as the treaty of peace had been ratified, in February, 1899, the contract was let for the manufacture of 212 miles of cable and the army transport *Hooker* was fitted out as a cable ship. The supervision of all matters connected with the manufacture, loading and subsequent care of the cable was entrusted to a Signal Corps officer. Major Joseph E. Maxfield

The *Hooker* arrived at Manila in July, 1899, but cable laying being delayed, she was sent by the Quartermaster's Department to Hong-Kong, and on her way out of Manila Bay was wrecked. By the most strenuous efforts of the signal officers all the cable machinery and instruments and most of the cable were taken off. A few months later the Signal Corps made its first essay in deep-sea cable laying in the Philippines. The cable machinery and the cable from the *Hooker* were put on a small coasting steamer chartered at Manila, and in the autumn of 1899, two lines of cable were laid, one connecting the islands of Leyte and Cebu, and the other the towns of Pasacao and Guinayangan on the west coast of Luzon. The subsequent use made of these cables and their great importance in the general scheme of communication have fully justified the original venture and emphasized the excellent work done in overcoming the obstacles presented by the wrecking of the *Hooker*.

The rapid spread of the American occupation in the southern islands of the archipelago soon made further provision necessary, and in the spring of 1900 active preparations were made for further extension of the cables. Seeing that a long period of cable laying was in prospect, Gen. Greeley, the Chief Signal Officer of the army, requested that a transport be assigned for that purpose. The transport *Burnside* was selected, thoroughly overhauled and refitted for use as a cable ship. Three cable tanks were put in, a testing room was built, and the forward deck was prepared for the placing of cable machinery as soon as the vessel arrived at Manila. Five hundred and fifty-three miles of deep-sea cable and eight miles of shore end were put aboard in New York. The *Burnside* arrived at Manila early in December, 1900, and was immediately fitted with the cable machinery originally sent out with the *Hooker*.

As this was the first deep-sea cable laying ever done by a ship regularly fitted out for that purpose by this Government, it may be interesting to describe personnel and material somewhat fully. The Chief Signal Officer of the Division of the Philippines Lieut.-Col. James Allen, Signal Corps, afterward Brigadier-General of Volunteers, was in charge of cable operations. He was assisted by a staff of five signal officers, Captains George O. Squiers and Edgar Russel and Lieutenants Henry S. Hathaway, Frederick W. Jones and Earle W. Binkley and two civilian experts, Mr. T. A. Hamilton, cable electrician, who had had previous distinguished service with commercial companies, and Mr. Henry Winter, cable engineer, who had also had great experience in cable laying and repairing. Seven enlisted men of the Signal Corps were regularly on board, a number of others being left as operators at various stations. Thirty-six natives were employed as laborers, their duties being mainly in the tanks during cable laying. The ship's officers and crew and the supply departments were under charge of an officer of the Quartermaster's Department, Major J. C. W. Brooks. The division of technical duties among the officers on board was made at once, although all took turns at watch at various important points when cable laying was in progress. As the duties were new to most of the officers and men, no opportunity for drill and instruction was lost, and, when once started, the work being almost incessant, great progress was made in a surprisingly short time.

The take-up gear used was made in New York. The cable coming up from the main tank through a bell mouth over the center passed over a fair lead, or sheave, and thence three or four times around the drum of the take-up gear, then through the dynamometer, and finally over either the bow or stern sheaves, circumstances determining whether cable should be laid over bow or stern. The testing room was fitted with an excellent assortment of instruments. Standard bridges, condensers, shunt-boxes, discharge and reversing keys, excellent galvanometers of the Sullivan and Thompson marine patterns and testing batteries were provided. The high insulation leads to the cable tanks were brought into the testing room in a secure and convenient way. The lower ends were fastened in boxes near the tanks, the terminals being kept dry by an electric lamp in each box.

During cable laying an officer was constantly on the bridge taking locations by sextant or compass observations every fifteen minutes. Another officer was in the cable tanks incessantly, watching the native laborers. He was provided with an electric signal for "full speed astern" in case a kink or snarl started up out of the tank, beyond control of the helpers. Another took general supervision of the machinery, seeing that proper amounts of water were used, and that all sheaves were kept oiled, the dynamometer closely observed, etc. The methods of getting the cable end ashore depended entirely on the peculiarities of the landing. Usually small boats in tandem, supporting the cable at intervals, were hauled shoreward by a rope running from the leading boat to a sheave secured on the beach, and thence back to a steam winch on the ship. Meantime while the shore end was being landed and trenched up to the office, or cable hut, the officer in charge of the office installation was engaged in constructing shelves and tables and setting up batteries and instruments.

Many of the Philippine cable stations were shared by soldiers of the garrison. In few cases was the white population other than military, and in some stations the cables were laid at a time when the sound of firing was a not infrequent accompaniment to the click of the office instruments. Many of the routes over which cables were laid were very imperfectly charted. In laying the cable from Iligan to Misamis, for example, along northern Mindanao an error of over five miles in a charted distance of twenty-five miles was discovered. This, taken in conjunction with numerous unchartered rocks and shoals and the absence of any shore lights, made navigation especially hazardous.

Owing to this uncertainty, and the meagreness or absence of soundings, it was necessary to precede each stretch of cable laying with a line of soundings. The Sigsbee sounding machine, utilizing piano wire and an iron detachable sinker, was used. The deepest soundings obtained were south of Mindanao when the line went down over 1200 fathoms. The heavy iron sinker failing to be detached, was brought up ice cold from this depth by the rapid little take-up gear attached to the sounding machine, an interesting exemplification of the fact that deep-sea temperatures are alike in torrid and frigid zones.

The first stretch of cable laid was that connecting Dumaguete, on the island of Negros, with Misamis, on the north coast of Mindanao, 98 nautical miles. All went well during the first 30 miles of laying, when a sudden "foul flake" appeared, carrying a mass of tangled cable up to the cable machinery and blocking it; although "full speed astern" was instantly signalled, the officer on watch sorrowfully noted the steady rise of the dynamometer until the 7000 lb. mark was reached, when the cable snapped and the end went overboard. Soundings were quickly taken and a mark buoy was soon placed. Four hundred fathoms was the depth at this point. The ship then went back about a mile, the grappling gear was lowered and slow dragging across our course was begun. The cable was soon caught, as indicated by the dynamometer, carefully raised, the bight cut and the end brought on deck. A test showed "all right," communication with the men on watch in the cable hut at Misamis being at once obtained. The splicing experts proceeded to splice the end to that of the cable in the main tank, the splice was lowered, and seven hours after the accident we were again under way, completing the laying of the cable without other incident. No accident exactly similar to this occurred in laying subsequent cables, but every other accident known to the profession did occur. Even an earthquake with a subaqueous landslide as a cable destroyer was provided for our especial benefit. So, instruction to the inexperienced was thorough, for thanks to a very capable cable engineer and the keen interest and hearty coöperation of all, every difficulty was successfully overcome.

On these lonely coasts many expedients were resorted to where difficult landings had to be made or cables were to be laid in shallow waters. One of these cases was the laying of a cable from Misamis south about 20 miles into Panguil Bay, a shallow body of water which nearly cuts the island of Mindanao in two at this place. The ship could not get any further than Misamis, so two native boats, called bancas, were hired, and the boats and outriggers were floored over. Cable was coiled on these, and taken up the bay and river by the ship's launches. The landing was at a deserted place in the Moro country called Lintogup. Here a cable hut was built, and, after many tribulations, the cable was laid back to Misamis, only to find that a fault had developed at the other end during the laying. Another weary repair journey across the treacherous wind-swept shallows had to be made. A land line connects the lonely hut at Lintogup with the cable station Tucuranon the south side of the Mindanao isthmus. From this point the cable goes to Zamboango.

Another coast cable has recently been laid connecting Tucuran with Malabang and Parang Parang. This is the country of the Moro savages, whom our soldiers have been compelled to chastise because of their failure to make restitution for robbery and the murder of Americans. The incalculable saving of time made by this complete system of cables connecting these places on Mindanao with Department Headquarters at Cebu and District Headquarters at Zamboango would be hard to estimate. Owing to the great distance from Manila, the supply departments would otherwise scarcely have been able to cope with the sudden demands made on them.

In the cable stations two methods of open-circuit Morse working were used,—the single and double current methods. In both, polarized relays were employed. An inspection of the diagrams (Figs. 1 and 2) shows the methods of connecting up. In only one of the cables, where the length was over 150 miles, was it found that the "k.r." was sufficient to make any troublesome drag in sending at moderate speeds by the single current method. At first the ordinary telegraph switchboards were used, but whenever testing had to be done the imperfect insulation given by these switchboards made the operations of "earthing," "freeing" and "cutting through" somewhat unreliable. Another form of switchboard for small stations has been devised. It is shown in the illustration (Fig. 3). It consists of a hard-rubber base on which are placed the ordinary straps, buttons and binding posts for a two-wire board. In addition two revolving slotted copper strips are shown for making connections, placing the cable to "instruments," "earth" or

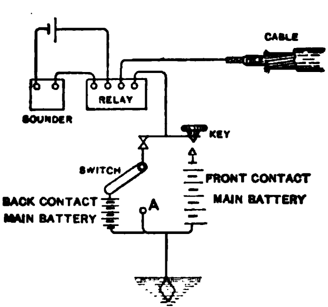


FIG. 1.

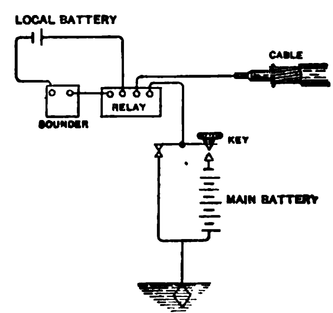
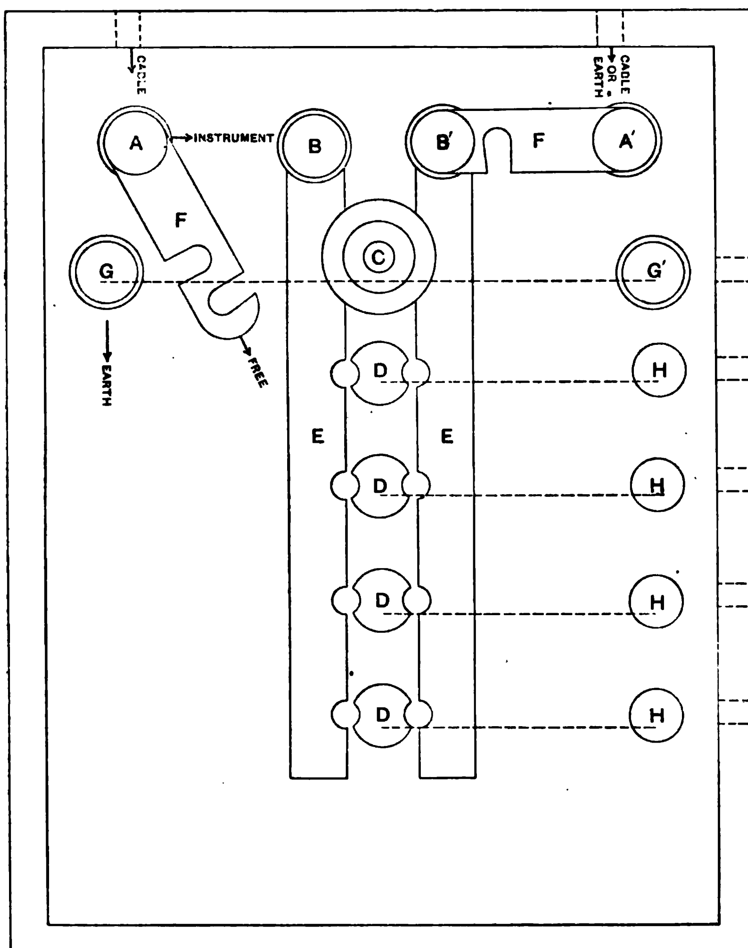


FIG. 2.

"free." The whole is fitted with a glass door and wooden cover of sufficient depth to admit placing a small cup of desiccating material within, when cable testing is going on.

In double current working a separate switch is needed in connection with the open circuit key to cut out the "back contact" battery when through working. This gives trouble to the operator accustomed to the ordinary switch lever, and the key illustrated was devised to overcome this difficulty. As will be seen, by altering the connections of the legs, the key may be used for either ordinary closed circuit, single, or double current open circuit. (Fig. 4). The ordinary sal-ammoniac batteries were used. It was found that very satisfactory service with the Stroh or Western Union form of polarized relay adopted, could be obtained with 15-milli-amperes, and the amount of battery was adapted to that strength of current. It was soon found in the Philippines that in no telegraph office could the ordinary office wire be depended upon. Consequently nothing but rubber-covered wire was permitted to be used in the cable offices, even on the local circuits.

These apparently trifling matters made much trouble until they



CABLE SWITCH BOARD

FIG 8.

were remedied. The great humidity and continuous high temperature produce remarkably rapid deterioration of all office material, and, it may be added, of the operators and officers as well. As it was desired in some instances to link a number of the local cables for through working, the open circuit repeater sets were devised. The wiring diagram and general design of one of the table sets are given in the illustrations. The complete instruments are mounted securely on telegraph tables, and the binding posts for attachment to the batteries and lines are plainly marked. The double switch in the center of the table provides changes of connections for independent working of the lines, or for repeating. In Fig. 5 and Fig. 6 are shown the wiring diagram and table top respectively.

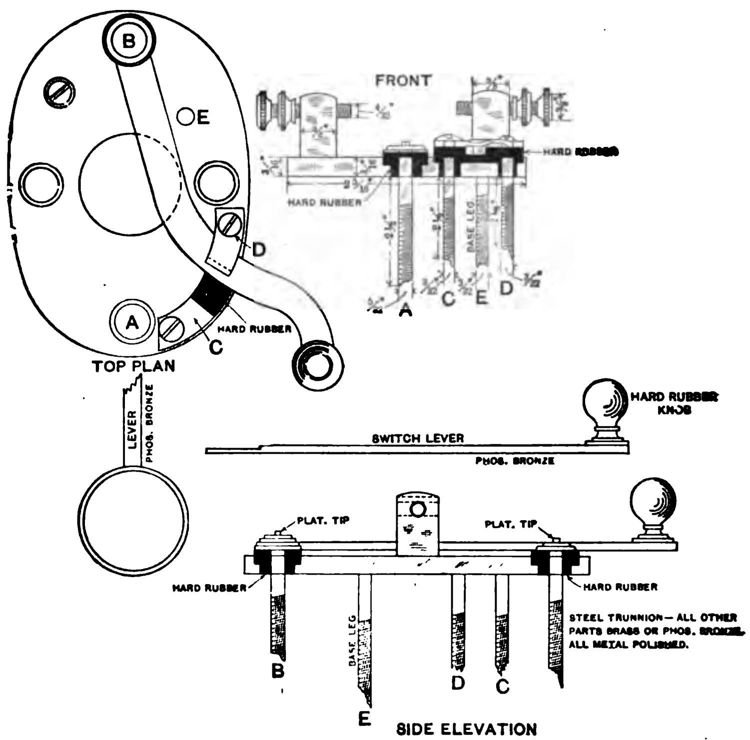


FIG. 4.—Combination key for open or closed circuit (single or double current). With relay connected to E. one pole of main battery to A, earth to C, and one pole of back contact battery to D, the key is suited for open circuit working either single or double current. (Single current with switch closed to left. By opening switch to right the back contact battery is put into circuit for double-current sending). By connecting A and C together, and E and B together, it may be used as an ordinary closed circuit key, A and B being the points connected with line and relay respectively.

Duplex sets have been procured and sent to the Philippines (for use over the cables and land lines) in charge of a number of Signal Corps men, trained especially in working and installing them. The sections over which they are to work are as follows:

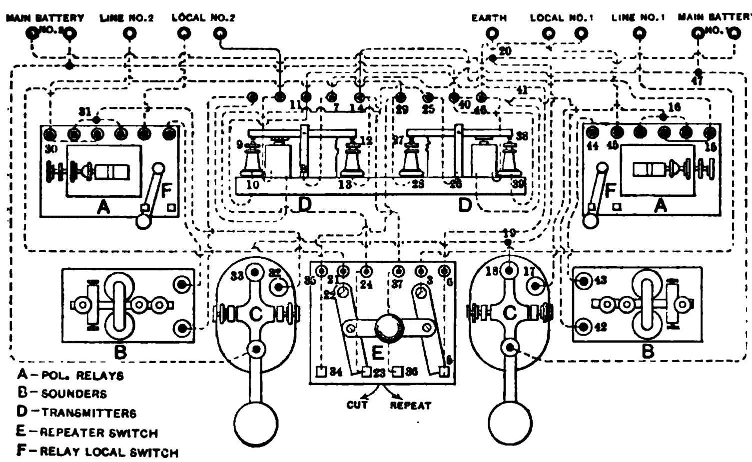
Manila-Guinayangan, 140 miles land line, polar duplex.

Guinayangan-Legaspi, 60 miles cable, 70 miles land line. differential duplex.

Legaspi-Calbayog, 157 miles cable, 10 miles land line, differential duplex.

Calbayog-Cebu, 140 miles cable, 35 miles land line, differential duplex.

These sections form an important line connecting Headquarters, Department of the Southern Philippines, at Cebu, with Headquarters, Division of the Philippines, at Manila. In the connecting lines there are 255 miles of land line, and 357 miles of cable. The differential duplex was adopted where a cable formed part of the line, in order to conform to open circuit conditions. The wiring diagram of the set for a station is given in Fig. 7. The instruments are ready mounted on two light telegraph tables, one for the sender and one for the receiver.



SIGNAL CORPS REPEATER SET.
SINGLE CURRENT OPEN CIRCUIT.

FIG 5.

At the same time that the men were being trained in duplex working, they were being instructed in the use of cable recorders and automatic transmitters. Sets of these instruments were procured from one of the best makers, and the men were constantly drilled in sending on the double key, in perforating tape for the automatic transmitter, and in reading the recorder tape. They had obtained a fair degree of proficiency in their eight-weeks' practice when they left for the Philippines. It is proposed to use these instruments over the new cable line between Batangas and Cebu direct. The sections between Marinduque, Romblon and Masbate islands are about to be laid. During most of the day it is proposed to work the line in sections by the ordinary open-circuit Morse; and at certain hours the local offices will be cut out, the lines will be linked together, and the routine reports, personal and press messages and other through business between Manila and Cebu, rapidly exchanged by means of the automatic transmitters, the tape having been prepared for this as messages are filed for transmission at Cebu or Manila.

If it be asked why this method of working is proposed, it may be said that the military land lines and cables, to a large extent, take the place of the letter mail in official and in much personal business. The average message is about 30 words in length, and for many months 10,000 messages per day have been trans-

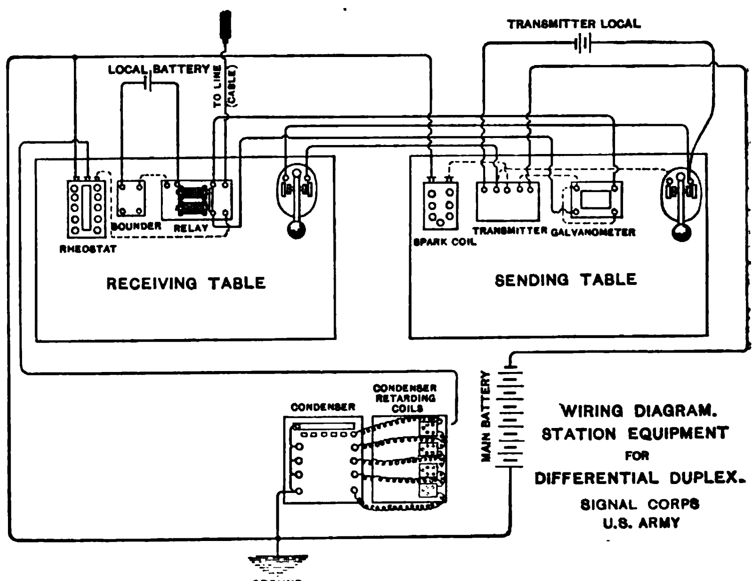


FIG. 6.

mitted over the Signal Corps line. It was ascertained by the Chief Signal Officer in the summer of 1901 that the average time required for sending letters from Manila to all telegraph offices on the Island of Luzon alone and getting replies, was about one month. It is proposed to try rapid telegraphy between Manila and Cebu to furnish some substitute for the slow mail communication. The local offices retain Morse working because it would not pay to put expensive and delicate instruments in each and train men to be experts to supply them.

Neither land lines nor cables were open, until quite recently, for commercial business and no statistics are at hand regarding a period of sufficient length to admit of estimates. The rates as first established were as follows:

1. Messages transmitted between points on the same island, two cents per word.

2. Messages between points on different islands, four cents per word.

3. Press specials, half rates.

Address and signature counted; the minimum charge is for ten words.

All of the cable laid in the Philippines by the Signal Corps has rubber insulation. For the trying conditions under which much of it had to be transported, stored and laid, there is no question that the choice of rubber over gutta-percha was a wise one. For example, much of the cable brought over on the *Hooker* was necessarily exposed to the weather for months before it could be laid. In that tropical climate gutta-percha cables would have been reduced to worthless junk, but the rubber cables had in many instances several hundred megohms dielectric resistance per knot, out of the original one thousand. The rubber insulation when immersed to depths of over 900 fathoms showed steady improvement as it went down. Two kinds of deep-sea cables are in the system, the data concerning these being briefly as follows:

	A.	B.
CONDUCTOR.	SEVEN NO. 24 COPPER.	SEVEN NO. 21 COPPER.
Diameter of Insulation.	8/32"	9/32"
Copper Resistance per knot	21.6 at 70° F.	9.7 at 60° F.
Dielectric " " "	1400 Meg. at 60° F.	750 Meg. at 75° F.
Capacity " "	.38 m.f.	.38 m.f.
Armor	16 No. 12 steel wires.	16 No. 10 steel wires.
Approx. weight per knot.	1.3 tons.	1.75 tons.

The core in each was taped, served with a double layer of jute, armored, then served with a double layer of jute and finished with a covering of compound and soapstone. The shore end cable was similarly made but received an additional armor of 18 No. 6 steel wires and another double layer of jute and compound. This shore end weighed about 6½ tons per knot.

The stations and distances in the cable system of the Philippines up to the present time, are given below:—

Laguna de Bay (Luzon)	Calamba-LosBanos	4	Miles
	Calamba-SantaCruz	18	"
	SantaCruz-Siniloan	9	"
Manila-Cavite, (Luzon)		8	"
Naic-Corregidor Island, (Luzon)		12	"
Guinayangan-Pasacao, (Luzon)		51	"

Legaspi-Bacon, (Luzon)	29	Miles
Sorsogon-Palanog (Masbate)	62	"
Batangas-Calapan (Mindoro)	30	"
Calapan-Boac (Marinduque)	45	"
Palanog-Calbayog (Samar)	75	"
Calbayog-Catbalogan (Samar)	37	"
Catbalogan-Carigara (Leyte)	45	"
Ormoc (Leyte)-Liloan (Cebu)	72	"
Liloan-Cebu) ?	13	"
Milagros (Masbate)-Capiz (Panay)	74	"
Argao (Cebu)-Loõn (Bohol)	14	"
Maasin (Leyte)-Surigao (Mindanao)	56	"
Oslob (Cebu)-Dumaguete (Negros)	17	"
Dumaguete-Misamis (Mindanao)	115	"
Misamis-Lintogup, Mindanao (no station)	23	"
Misamis-Iligan (Mindanao)	32	"
Iligan-Cagayan (Mindanao)	60	"
Tucuran (Mindanao)-Malabang (Mindanao)	48	"
Malabang-Parang Parang	24	"
Tucuran-Zamboanga (Mindanao)	158	"
Zamboango-Jolo (Jolo)	100	"
Zamboango-Isabela (Basilan)	18	"
Jolo-Siassi (Siassi)	50	"

In all there are 41 cable stations with 1297 miles of cable con necting them.

There was plenty of theoretical knowledge as to cables and cable methods among the officers of the Signal Corps when the development of this system was inaugurated. It is needless to say to the members of this Institute that theory and practice are two different things. Thanks to the resourcefulness of the American soldiers and the American officers, supplemented by most valuable advice from the civilian cable engineers, Hamilton and Winter, the officers and men of the Signal Corps speedily developed into a most efficient cable force. Whether it was a question of laying, recovering, splicing, repairing or installing, the time soon came when work of this character was done with clockwork regularity and with the greatest economy of time and effort.

It may be of interest to state that prophesies were not lacking that American-made cable would not suit the physical conditions of the Philippine archipelago. As an answer, it may be said that of the 29 separate submarine cables installed, not one has failed through defects of manufacture or installation. The only interruptions have been due to mechanical injuries arising almost entirely from ships' anchors and similar accidents. Perhaps there may be considered one exception, where a small piece of cable developed some weaknesses in insulation during the installation, which being removed, the cable has worked uninterruptedly for the past 18 months. It may be added that large quantities of this cable, owing to scarcity of funds, were made under Signal Corps specifications of the cheapest possible type consistent with the work expected of it, scarcely exceeding one ton per statute mile.

It is not the purpose of this paper to speculate upon the future telegraphic conditions in the Philippines, but to attempt to show under what novel and difficult conditions the pioneer work in this field has been accomplished by the Signal Corps. The use of the best or most approved telegraphic methods, common in this or other countries, has not always been considered advisable, for the men are in most cases so much needed to fill the vacancies due to breakdowns in health, on account of the trying tropical climate, that little opportunity for preliminary training has been afforded. Furthermore, the great distance from the base of supplies makes it necessary to be very conservative in adopting appliances not proved efficient by long tests under similar conditions. The value of the telegraphic and cable work of the Signal Corps has been referred to in almost every report from district, department and division commanders, so it is pleasant to feel that success has crowned the work of the corps, and a good foundation has been laid for those who come after.

This resumé of the past would not be complete without a brief allusion to the cable situation in the Orient. It is a matter of record that France, Germany, Great Britain, Holland and Russia have greatly extended their cable facilities along the Asiatic coast. All island colonies have been or are now in the process of connection by cables with the principal colonial stations of each nation of the Asiatic mainland. Alone of all countries the United States, which has constructed in an unparalleled short time a magnificent system of nearly 8,000 miles of telegraph lines and cables in the Philippine archipelago, refrains from taking steps to connect this archipelago either with Japan to the north, Australia to the south, or most important, with China to the west. It is believed that the engineering interests of the United States, which have forged to the front in Europe and Africa, will at an early date insist on additions which will foster the growth of American industry and commerce in the far East.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28, 1902.

THE REASONS FOR THE CHANGE OF THE NAVY STANDARD VOLTAGE FROM 80 TO 125.

BY LIEUT. W. V. N. POWELSON, U. S. N.

Before proceeding to a discussion of the considerations which led to the recent adoption by the Navy Department of 125 volts as the standard for all new installations on board ship, it may not be out of place to review briefly the history of the voltages used by the navy.

In the first installations, and previous to 1888, two voltages were used on board the same vessel. Generators of 110 volts were used for supplying power for the incandescent lights and generators of 50 volts were employed for the operation of the searchlights.

In May, 1888, a board was appointed to decide upon a single standard voltage at which power might be supplied to operate both the incandescent lamps and the searchlights. This board as a compromise selected a voltage of 80, the mean of the voltages already in use.

One very important consideration at that time which prevented the adoption of the commercial voltage of 110 as the standard was no doubt the apparently enormous waste of energy in the rheostat that had to be employed to cut down the voltages from 110 to about 45, the arc voltage of the searchlights at that time.

It must be remembered that the searchlights in the early installations required a very large percentage of the total electrical energy developed on board ship, and therefore their position was a most important one in any discussion affecting the voltage of the generators. Now the position occupied by the searchlights in relation to the total power developed is minor.

Since 1888 the standard voltage of the generators on board ship has been 80, and the difference of potential between all distributing lines has been 80 volts except in the *Kearsarge*, and in the *Kentucky*, battleships of about 12,000 tons, commissioned in 1899. In these ships a new and radical departure was made in the system of distributing power. The generators were wound for 80 volts, but the wiring arrangements were such as to permit of the transmission of energy on either the two-wire 80-volt system or the three-wire system with 160 volts difference in potential between the outside wires. Although a discussion of the advantages and disadvantages of this system compared with an 80-volt two-wire system would no doubt prove of interest, it is beyond the scope of the present paper.

The attention of the Navy Department, in 1901, was strongly drawn to the necessity of changing the standard voltage 80 by the difficulty which was experienced in the purchase of electrical material owing to its special character, and one year ago a board was appointed to consider again the question of a standard voltage for the navy. Since any increase of voltage would permit of a reduction in the size of the transmission lines, it was desired to raise the voltage to that limit where the advantages to be derived from this circumstance began to be outweighed by certain disadvantages.

These disadvantages might result from the difficulty of making lamps for the particular voltage, from the fact that the voltage was not commercial or from the danger from shocks, bad arcing, grounds and electrolytic action due to moisture getting into the water-tight boxes.

The voltages from which the choice might be made were 110, 125, 220, 250, 500 and 550. In view of the recommendation of the Committee on Standards of this INSTITUTE the choice was narrowed down to 125, 250 and 550 volts. One hundred and ten volts was passed because 125 volts possessed all the advantages of a 110-volt system with certain additional advantages, and no additional disadvantages except in the matter of operation of the searchlights. At that time the plant of the *Kearsarge* had been running for some months with a difference of potential of 160 volts between wires and no bad effects had been noted from shocks, arcing, grounds or electrolytic action, and no trouble on this score was therefore to be expected from the use of 125 volts.

Two hundred and fifty and 550 volts were discarded for the following reasons:

(*a*) The difficulty that it was expected would accompany the purchase of satisfactory incandescent lamps.

(*b*) The additional waste of power in operating searchlights.

(*c*) The probable necessity of re-designing the standard wiring appliances.

(*d*) The very large increase over any voltage formerly used on board ship.

In considering the question of a change of voltage inquiry was made to determine:

(*a*) What advantages would be secured by the adoption of a voltage from the mere fact that it was commercial. irrespective of any consideration of its absolute value.

(*b*) What effect would a change to the most suitable commercial voltage have upon the cost and weight of electrical apparatus used on board ship.

(*c*) What effect would a raise in voltage have upon the efficiency of operation of electrical apparatus on board ship.

ADVANTAGES OF USING A COMMERCIAL VOLTAGE.

An advantage which is always sure to follow the adoption of a commercial article is a large reduction in the time of delivery and in any naval organization this may become of supreme importance. It does not always follow that a reduction in price will result. This will depend upon how special the former apparatus was and in how large quantities it was purchased. Take for instance the incandescent lamps. The navy has been buying a special 16 c.p. lamp of 80 volts, 3.8 watts efficiency and equipped with a bulb of special shape. Notwithstanding the special character of this lamp the navy has not paid a higher price than a commercial lamp would cost, for two reasons:

(*a*) Because the limits of variation in volts and watts per candle at the rated candle power have been so large, viz: 78 to 82 volts and 3.6 to 4.0 watts, and

(*b*) Because lamps have been ordered in fairly large quantities.

It must be apparent that if a special voltage is used a purchaser must pay more for his lamps than the price of a commercial article, or he must allow such variations in the volts and watts per candle as will permit a manufacturer to make up a lot of lamps practically all of which will fall between the limits allowed. If the limits are so narrow that on an average only half of the finished lamps fall between the allowed limits, the manufacturer must charge double if the voltage is so special that the other lamps cannot be sold.

If a purchaser who has been buying lamps of special voltage orders lamps, however, of any voltage between 100 and 125, he may reduce the limits of variation in volts and watts per candle without any increase in price because there is a demand for lamps of all voltages from 100 to 125, and the lamps which fall outside his limits may readily be sold to someone else and the manufacturer suffers no loss. In the purchase of lamps, therefore the advantages to be derived from the adoption of a commercial voltage are:

(*a*) quick deliveries,

(*b*) closer selection.

These advantages will, however, not be secured if any of the required features of the lamps are special. A special shape of bulb or a special wattage would at once defeat both of the advantages which might be derived.

In the matter of generators and motors the possible advantages to be derived from the adoption of a commercial voltage are :

(*a*) quick deliveries,

(*b*) decreased cost.

Whether or not these advantages will be secured, depends almost entirely upon whether the navy adopts the heating limits allowed in commercial work, *i. e.*, the limits recommended by the Committee on Standards of this INSTITUTE.

The navy's heating limits are at the present time considerably below the commercial limits and a commercial generator or motor must be re-designed in its windings and re-rated at a lower rating in order to meet the navy specifications. Unless the commercial heating limits are adopted, our generators and motors will still be special and no advantage, either in price or time of delivery, is likely to follow a change to a commercial voltage.

In the matter of insulated wire, however, a change to a commercial voltage will secure the only advantage possible—that of decreased cost—and this advantage will be fully obtained without regard to the special character of the wire used, for the reason that any increase in voltage will permit the size of wire to be reduced and the navy standard thickness of insulation is strong enough to withstand easily any commercial low tension voltage.

In order to determine how much of a saving in cost and weight of wire and conduit would result in a battleship of the size of the *Kearsarge* if the voltage were raised from 80 to 125 when using a plain two-wire system, certain calculations were made as shown in Tables 1 to 9.

So much has been claimed for the three-wire system as installed on the *Kearsarge* in the matter of saving in cost and weight of wire that it was decided to include in the tables above mentioned the cost and weight of the wiring as actually installed so that a comparison might also be made between this system and the two-wire 125-volt system.

Before proceeding to a discussion of the tables it would be well to consider briefly the system of transmission actually installed on the *Kearsarge*. This system is shown diagrammatically in Fig. 1.

From the dynamo-room, power is transmitted to distributing boards forward and aft. The transmission is divided into two sections—one for power and one for lighting. Energy is distributed from the dynamo-room to the larger distribution boards on the three-wire system, employing five wires, the neutral being common to both power and lighting systems. From the distribution boards all the lighting is on the two-wire 80-volt system, while the power distribution is, with the exception of certain small motor circuits, all on the three-wire system. All the switchboards are, however, so arranged that the outside wires of the three-wire system may be placed in parallel, so that any part of the system may be worked with only one dynamo in operation at a pressure of 80 volts. In order that the system might be thus operated it was necessary to make the neutral wire of the power system the same size as the outside wires, for the reason that the neutral must when thus employed take the sum of the currents in the outside wires. When working under 80 volts pressure the current taken by the motors is approximately one-half the full load current, so that under these working conditions the neutral is taking a current equal to the full load current of an outside wire, when working the motors at 160 volts, and the neutral must therefore have the same section as the outside wires.

WEIGHTS.

Electric Machinery.—The weight of a dynamo or motor of a given output is practically independent of the voltage for which it is wound. The only dimensions of such machines that would vary appreciably for a given output with a moderate change of voltage would be the commutator dimensions. The surface of a commutator would vary inversely as the voltage and its weight in a somewhat smaller proportion. It is estimated that a saving of not more than 1½% in the total weight of a generating set could be effected by increasing its voltage from 80 to 125, and of not more than 2% in the weight of an enclosed motor by a similar increase in voltage. This saving would result only on the assumption that each machine was accurately designed for its rated voltage. In practice it is doubtful whether there would be any saving at all, for it is the custom to work up standard commercial forms into something that will be just under the weight limit allowed by specifications

Transmission Lines.—Except in a very few cases the size of all transmission lines on board ship is determined on the basis of a certain maximum allowable drop in voltage between the switchboard and the last lamp or motor, as the case may be. In other words, the lines are calculated for a given allowable percentage of loss of energy under full load. If, therefore, two transmitting systems of different potential are to be directly comparable, as regards the size of conductors, each must give the same efficiency of transmission. The sizes of the conductors in the two systems would vary in section inversely as the square of the voltage of the systems. In a 125-volt system, therefore, conductors could be employed having but 41% of the copper section of conductors in an 80-volt system. The total weight of the corresponding insulated wires in the two systems would not, however, have the fixed ratio of 41%, because the weight of the insulation is not a fixed percentage of the total weight of the wire for all sizes. The thickness of the navy standard insulation is practically independent of the size of wire, and hence in the smaller wires it is a larger proportion of the total weight of wire than in the larger sizes. This is shown in Table 1, column 5. There is a certain saving in weight due to an increase in voltage on all wires except No. 14 B. & S. of 4,000 cm., and the double conductor of seven strands of No. 22 B. & S. used so largely in portables. It was not con-

TABLE I.

SHOWING THE DETAILED COST AND WEIGHT OF BOTH INSULATION AND COPPER OF WIRES USED AS FEEDERS ON KENTUCKY AN. KEARSARGE.

	Circular mils of copper in feeders. (1)	Total weight of wire per foot. (2)	Weight of copper per foot. (3)	Weight of insulation per foot. (4)	Percentage of total weight of wire. (5)		Total cost of insulated wire per foot. (6)	Cost of copper in wire per foot. (7)	Cost of insulation on wire per ft. (8)	Percentage of total cost of wire. (9)	
					Copper.	Insulation.				Copper.	Insulation.
1	1,321,308	4.60	4.00	.600	87.0	13.0	1.60	.80	.80	50.0	50.0
2	1,045,718	3.60	3.16	.440	87.8	12.2	1.33	.632	.698	47.5	52.5
3	829,310	2.90	2.51	.390	86.5	13.5	1.05	.502	.548	47.8	52.2
4	657,606	2.313	1.986	.327	86.0	14.0	.84	.397	.443	47.2	52.8
5	521,589	1.885	1.570	.315	83.3	16.7	.72	.314	.406	43.6	56.4
6	413,639	1 553	1.250	.303	80.5	19.5	.56	.250	.310	44.5	55.5
7	373,737	1.420	1.129	.291	79.5	20.5	.48	.226	.254	.47.0	53.0
8	296,387	1.138	.895	.243	78.6	21.4	.39	.179	.211	46.0	54.0
9	250,527	.970	.756	.214	78.0	22.0	.35	.1512	.1988	43.2	56.8
10	198,677	.794	.599	.195	75.5	24.5	.30	.1198	.1802	40.0	60.0
11	157,563	.647	.475	.172	73.5	26.5	.25	.0950	.1550	38.0	62.0
12	124,928	.546	.378	.168	69.4	30.6	.22	.0756	.1444	34.4	65.6
13	99,064	.403	.299	.164	64.5	35.5	.20	.0598	.1402	29.9	70.1
14	75,776	.371	.229	.142	61.8	38.2	.15	.0458	.1042	30.5	69.5
15	60,088	.314	181	.133	57.6	42.4	.12	.0362	.0838	30.2	69.8
16	49,077	.260	.148	.112	57.2	42.8	.10	.0296	.0704	29.6	70.4
17	38,912	.218	.117	.101	53.5	46.5	.09	.0234	0666	26.0	74.0
18	30,912	.184	.093	.091	50.5	49.5	.08	.0186	.0614	23.2	76.8
19	22 779	.165	.069	.096	42.0	58.0	.075	.0138	.0612	18.4	81.6
	Average	1.28					.47				

TABLE II.

TABLE SHOWING THE PERCENTAGE IN COST AND WEIGHT OF THE WIRES WHICH WILL GIVE THE SAME EFFICIENCY IN TRANSMISSION OF POWER UNDER A 125 VOLT SYSTEM, AS THE WIRES IN TABLE I WILL GIVE UNDER THE 80 VOLT SYSTEM.

	C.M. of copper in 125 v. cable. Comp. to wires in table 1. 41 per cent. of col. 1, table 1. (10)	Calculated wt. of cu. in. wire = 41 per cent. of col. 3, table 1. (11)	Calculated wt. of ins. on wire = 64 per cent. of col. 4, table 1. (12)	Calculated weight of ins. wire per foot. (13)	Actual wt. of ins. wire per foot from tables. (14)	Total cost of insulated wire per foot. (15)	Col. 14/col 2. Ratio of total wt. of wire in 125 v. sys. to wt. in 80 v. sys. (16)	Col. 15/col. 6 Ratio of total cost of wire in 125 v. sys. to cost in 80 v. sys. (17)
1	542,000	1.64	.384	2.024	1.95	.74	.424	.463
2	430,000	1.29	.282	1.572	1.60	.58	.445	.443
3	340,000	1.03	.250	1.280	1.30	.44	.448	.419
4	270,000	.813	.209	1.022	1.04	.37	.449	.440
5	214,000	.645	.203	.848	.85	.32	.451	.444
6	169,500	.512	.194	.706	.695	.265	.447	.473
7	153,000	.463	.186	.649	.634	.246	.456	.513
8	121,500	.366	.156	.522	.533	.217	.469	.553
9	102,500	.310	.137	.447	.473	.202	.487	.577
10	81,500	.246	.125	.371	.394	.163	.496	.544
11	64,500	.195	.110	.305	.330	.129	.510	.516
12	51,200	.155	.108	.263	.270	.102	.495	.464
13	40,500	.123	.105	.228	.225	.092	.486	.460
14	31,000	.094	.091	.185	.188	.081	.506	.540
15	24,600	.074	.085	.159	.170	.076	.542	.634
16	20,100	.061	.072	.133	.145	.070	.560	.700
17	15,950	.048	.065	.113	.128	.0636	.585	.650
18	12,620	.038	.058	.096	.114	.0590	.610	.675
19	9,350	.028	.061	.089	.1065	.0510	.645	.680
	Average.....				.587	.225		

TABLE III.

SHOWING SIZE AND COST OF ENAMELED CONDUIT FOR FEEDERS OF VARIOUS SIZES USED ON THE KENTUCKY AND KEARSARGE.

	Size of feeders in 80-volt system from column 1. (18)	Overall diameter of wire. (19)	Standard size of conduit (20)			Clearance. (21)	Weight of conduit per foot of conductor (22)	Cost of conduit per foot of conductor (23)
			Wiresper tube.	Bore.	I. P. S			
1	1,321,308	1.688	1	2.06	2"	.313	Lbs. 3.61	$.23
2	1,045,718	1.520	1	2.06	2"	.540	3.61	.23
3	829,310	1.375	1	1.58	1½"	.205	2.68	.17
4	657,606	1.250	1	1.58	1½"	.330	2.68	.17
5	521,589	1.156	1	1.58	1½"	.424	2.68	.17
6	413,639	1.062	1	1.35	1¼"	.290	2.24	.13
7	373,737	1.031	1	1.35	1¼"	.320	2.24	.13
8	296,387	.937	1	1.35	1¼"	.413	2.24	.13
9	250,527	.875	1	1.35	1¼"	.475	2.24	.13
10	198,677	.813	1	1.02	1"	.208	1.67	.11
11	157,563	.750	1	1.02	1"	.270	1.67	.11
12	124,928	.718	1	1.02	1"	.302	1.67	.11
13	99,064	.687	2	1.58	1½"	.206	1.34	.085
14	75,776	.625	2	1.35	1¼"	.100	1.12	.07
15	60,088	.593	2	1.35	1¼"	.164	1.12	.07
16	49,077	.563	2	1.35	1¼"	.225	1.12	.07
17	38,912	.531	2	1.35	1¼"	.288	1.12	.07
18	30,912	.500	2	1.35	1¼"	.350	1.12	07
19	22,779	.500	2	1.35	1¼"	.350	1.12	.07
	Average...						Lbs. 1.96	.122

TABLE IV·

SHOWING THE PERCENTAGE IN COST AND WEIGHT OF THE ENAMELED CONDUIT FOR WIRES WHICH WILL GIVE THE SAME EFFICIENCY IN TRANSMISSION OF POWER UNDER A 125 VOLT SYSTEM, AS THE WIRES IN TABLE 3 WILL GIVE UNDER AN 80 VOLT SYSTEM.

	Size of feeders in 125-volt system from column 10.	Overall diameter of wire.	Standard size of conduit. (26)			Clearance.	Weight of conduit per foot of conductor.	Cost of conduit per foot of conductor.	Ratio of cost of conduit for 125-v. system to cost of cond. for 80 v. sys. Col. 29/col. 23.	Ratio of wt. of conduit for 125 v. system to wt. of cond. for 80 v. sys. Col. 28/col. 22.
			Wires per tube.	Bore.	I. P. S.					
	(24)	(25)				(27)	(28)	(29)	(30)	(31)
1	542,000	1.170	1	1.38	1½"	.410	Lbs.2.68	$ .170	.740	.742
2	430,000	1.075	1	1.35	1¼"	.275	2.24	.130	.565	.620
3	340,000	.980	1	1.35	1¼"	.370	2.24	.130	.765	.835
4	270,000	.902	1	1.35	1¼"	.448	2.24	.130	.765	.835
5	214,000	.830	1	1.02	1"	.190	1.67	.110	.648	.623
6	169,500	.770	1	1.02	1"	.250	1.67	.110	.847	.745
7	153,000	.750	1	1.02	1"	.270	1.67	.110	.847	.745
8	121,500	.712	2	1.58	1½"	.156	1.34	.085	.655	.598
9	102,500	.690	2	1.58	1½"	.200	1.34	.085	.655	.598
10	81,500	.638	2	1.58	1½"	.304	1.34	.085	.773	.803
11	64,500	.600	2	1.35	1¼"	.150	1.12	.070	.637	.680
12	51,200	.570	2	1.35	1¼"	.210	1.12	.070	.637	.680
13	40,500	.540	2	1.35	1¼"	.270	1.12	.070	.825	.835
14	31,000	.500	2	1.35	1¼"	.350	1.12	.070	1.000	1.000
15	24,600	.500	2	1.35	1¼"	.350	1.12	.070	1.000	1.000
16	20,100	.500	2	1.35	1¼"	.350	1.12	.070	1.000	1.000
17	15,950	.450	2	1.02	1"	.120	.83	.055	.786	.746
18	12,620	.438	2	1.02	1"	.145	.83	.055	.786	.740
19	9,350	.438	2	1.02	1"	.145	.83	.055	.786	.740
	Average .						Lbs. 1.46	.091		

TABLE V.

SHOWING DETAILED COST AND WEIGHT OF THE WIRE IN LIGHTING CIRCUITS ON KENTUCKY AND KEARSARGE, UNDER A TWO WIRE 80 VOLT, AND A TWO WIRE 125 VOLT SYSTEM. THE SIZES IN COLUMN 1 ARE THOSE ACTUALLY INSTALLED ON THE SHIP, EXCEPT CABLES 12 AND 13. THESE CABLES ARE FOUR TIMES THE SIZE OF THOSE INSTALLED. THESE WIRES FORM, IN THE ACTUAL INSTALLATION, PART OF A THREE WIRE SYSTEM, AND THE ONLY PART OF SUCH SYSTEM CONNECTED WITH THE LIGHTING SYSTEM. TO REDUCE THE SYSTEM TO A PURELY TWO WIRE SYSTEM, THE NEUTRAL WIRE WAS DISREGARDED, AND THE OUTSIDE WIRES INCREASED TO FOUR TIMES THE SIZE INSTALLED. THE COSTS AND WEIGHTS WERE OBTAINED FOR THE 125 VOLT SYSTEM, BY MULTIPLYING THE COSTS AND WEIGHTS FOR THE 80 VOLT SYSTEM BY THE MULTIPLIERS FROM COLUMN 16 AND COLUMN 17, TABLE 2.

	(1) Size in cm. in 80 volt 2 wire system.	(2) Length of wire in feet.	(3) Cost in 80 volt 2-wire system.	(4) Weight in 80 volt 2-wire system. in lbs.	(5) Cost in 125 volt 2-wire system.	(6) Weight in 125 v. 2-wire system in lbs.	(7) Saving in cost. Col. 3 minus col. 5.	(8) Saving in wt. Col. 4 minus col. 6. Lbs.
1	Double Cond.. 7-No.22 B & S	9,495	$1,045.00	1,723.34	$1,045.00	1,723.34	$00.00	00.00
2	4,107	19,314	580.00	1,098.97	580.00	1,098.97	00.00	00.00
3	9,016	1,587	79.20	163.46	47.50	90.25	31.70	73.21
4	11,368	203	10.15	21.93	6.20	13.20	3.95	8.73
5	18,081	1,833	128.20	256.62	91.50	187.60	36.70	69.02
6	22,799	1,838	137.20	303 27	93.50	195.00	43.70	108.27
7	30,856	1,785	142.70	328.07	110.40	200.00	32.30	128.07
8	38,912	1,402	126.20	305.64	89.20	178.50	37.00	127.14
9	49,077	1,030	103.00	267.80	72.10	140.60	30.90	118.20
10	60,088	1,585	190.00	497.69	126.70	286.00	63.30	211.69
11	75,776	942	142.20	349.48	81.00	176.00	61.20	173.48
12	1,654,556	486	974.00	2,800.00	457.50	1,154.00	516.50	1,646.00
13	2,630,424	84	268.00	774.00	126.00	326.00	142.00	448.00
	Two cables in	parallel,	each 1,315	,212 c.m				
	Total.		$3,925.85	8,890.27	$2,926.60	5,778.46	999.25	3.111 81

TABLE VI.

SHOWING RELATIVE COSTS OF POWER WIRING ON KENTUCKY AND KEARSARGE UNDER THE 160 VOLT SYSTEM (3 WIRE) AS INSTALLED UNDER AN 80 VOLT (2 WIRE) AND A 125 VOLT SYSTEM (2 WIRE). IN THE THREE WIRE 160 VOLT SYSTEM ACTUALLY INSTALLED, THE NEUTRAL IS OF THE SAME SIZE AS THE OUTSIDE WIRES

A.

	(1) Size of power wires installed in 160 volt system (3 wire.) C M.	(2) Total length of wire installed in the 3-wire system in feet	(3) Total length of wire in any 2-wire system in feet. $\frac{2}{3}$ of col 2.	(4) Size in c.m. in 80 volt 2-wire system 4 × col. 1	(5) Size in c.m. in 125 volt 2-wire system 41 per cent col. 4.	(6) Cost in 160 volt system (3-wire) as installed	(7) Cost for 80 volt 2-wire system	(8) Cost for 125 volt 2-wire system.	(9) Weight for 160 volt system (3-wire) as installed.	(10) Weight for 80 volt 2-wire system	(11) Weight for 125 volt 2-wire system.
									Pounds	Pounds	Pounds
1	22,799	2,180	1,452	89,196	36,600	$163.50	$256.10	$129.25	360.20	667.50	328.00
2	30,856	898	600	123,424	50,600	71.80	130.30	65.30	165.23	330.00	155.00
3	38,912	683	455	155,648	63,800	61.50	112.25	56.30	148.89	296.00	135.50
4	49,077	2,270	1,513	196,308	80,100	227.00	447.50	220.00	590.20	1,191.50	543.00
5	60,088	1,660	1,170	240,352	98,500	199.50	392.60	193.50	521.87	1,089.00	496.00
6	75,776	1,524	1,016	303,104	124,200	228.10	405.00	192.20	566.40	1,185.00	540.00
7	99,064	696	462	396,256	162,300	139.20	257.00	119.50	322.25	489.00	221.10
8	124,928	424	283	499,712	223,000	93.30	195.30	88.00	236.17	505.00	226.50
9	157,568	902	602	630,252	258,100	225.50	485.00	228.00	583.59	1,340.00	610.00
10	198,677	507	338	794,708	325,800	152.10	340.00	154.50	402.56	940.00	427.50
11	250,527	1,056	704	1,002,108	411,000	369.00	895.00	405.00	1,024.32	2,440.00	1,085.00
12	296,387	296	197	1,185,548	486,500	115.00	283.00	122.50	336.85	805.00	336.00
13	413,639	181	121	1,654,556	678,500	101.30	242.00	105.00	281.09	698.00	290.00
14	657,606	1,363	883	2,630,424	1,078,000	1,190.00	2,817.00	1,163.00	3,271.20	8,000.00	3,296.00
15	829,310	456	304	3,316,930	1,365,000	478.00	1,260.00	504.00	1,321.00	3,465.00	1,440.00
	Total					3,814.80	8,518.05	3,746.05	10,131.82	23,431.00	10,129.60

B.

IN COLUMN I. THE ACTUAL SIZES OF THE WIRES INSTALLED ARE GIVEN. THESE WIRES ARE RUN ON AN 80 VOLT TWO WIRE SYSTEM. TO CERTAIN OF THE SMALLER MOTORS, ETC.

(1) Sizes actually installed on an 80 volt two-wire system.		(2) Actual length installed. Feet.	(3) Total length of wire in any 2-wire system Feet.	(4) Size in cm. in 80 volt 2-wire system.	(5) Size in cm. in 125 volt 2-wire system. 41 per cent. col. 4.	(6) Cost as installed.	(7) Cost for 80 volt two-wire system.	(8) Cost for 125 volt two-wire system	(9) Weight as installed. Pounds.	(10) Weight for 80 volt 2-wire system. Pounds	(11) Weight for 125 volt 2-wire system. Pounds.
1	4,107	285	285	4.107	4,107	$8.55	$8.55	$8.55	16.22	16.22	16.22
2	9,016	922	922	9 016	4,107	45.08	45.08	27.66	92.27	92.27	52.50
3	11,368	432	432	11.368	4,660	25.92	25.92	21.50	46.87	46.87	33.26
4	18,081	160	160	18,081	7.400	11.20	11.20	8.00	22.40	22.40	16.00
5	22,799	110	110	22,799	9,310	8.25	8.25	5.61	18.15	18.15	11.60
6	49,077	200	200	49,077	20,100	20.00	20.00	14.00	52.00	52.00	29.00
7	99,064	320	320	99,064	40,500	64.00	64.00	29.12	148.16	148.16	74.22
Total						183.00	183.00	114.44	396.07	396.07	232.80
Total from "A"...						3.814.80	8,518.05	3,746.05	10.131.82	23,431.00	10.129.60
Grand Total						3,997.80	8.701.05	3,860.49	10,527.89	23,827.07	10,362.40

Saving in cost of wire alone in the 160v. (3 wire) system, as installed, over the 80v (2 wire) system	$5,618.33
" " " " " " " 125v. (2 wire) " over the 80v (2 wire) system........	6,087.65
" " " " " " " " " " " " 160v. (3 wire) system as installed........	469.32

Saving in weight of wire alone in the 160v. (3 wire) system, as installed, over the 80v (2 wire) system........	Lbs 15,916.82
" " " " " " " 125v. (2 wire) " over the 80v. (2 wire) system........	" 17.283.33
" " " " " " " " " " " " 160v. (3 wire) system as installed........	" 1.366.51

	Insulated Wire. Cost.	Insulated Wire. Weight.
Ratio of 160 v. (3 wire) sys. as installed to 80 v. (2 wire) system..	.588	.553
" " 125v. (2 wire) sys. to 80v. (2 wire) sys	.554	.515
" " " " " 60v. (3 wire) sys. as installed......	.938	.930

TABLE SHOWING DETAILED COSTS AND WEIGHTS OF THE WIRING ON U. S. S. KEARSARGE AND KENTUCKY UNDER THE THREE-WIRE 160 VOLT SYSTEM AS INSTALLED. A 2 WIRE 80 VOLT SYSTEM, AND A 2 WIRE 125 VOLT SYSTEM

TABLE VII.

DYNAMO AND EQUALIZER LEADS.

THESE WOULD BE THE SAME FOR A THREE WIRE AS FOR A TWO WIRE SYSTEM, IF THE GENERATORS WERE WOUND FOR THE SAME VOLTAGE IN EACH, BUT IN CHANGING DYNAMO E.M.F. FROM 80 TO 125 VOLTS, AND KEEPING CURRENT DENSITY IN LEADS THE SAME, A REDUCTION CAN BE MADE IN THE SIZE OF THE LEADS, IN THE PROPORTION OF 80 TO 125. THE EQUALIZER LEADS WERE KEPT AT THE ORIGINAL SIZE AS INSTALLED.

Size in C.M. 80 volts.	Size in C.M. 125 volts.	Length in ft.	Wt. in lbs. at 80 volts.	Wt. in lbs. at 125 volts	Cost at 80 volts.	Cost at 125 volts.
4,106	4,106	455	25.89	25.89	$13.65	$13.65
30,856	19,750	306	56.30	44.17	24.48	21.10
38,912	25,400	112	24.42	14.05	10.08	8.96
829,310	530,000	181	570.15	344.00	190.00	133.00
1,045,718	672,000	399	1,455.20	997.00	530.00	343.66
Equal'r lead 1,045,718	1,045,718	199	727.50	727.50	265.00	265.00
Total......			2,859.46	2,152.61	1,033.21	785.37

TOTAL COSTS AND WEIGHTS.	As installed. A combination of an 80 volt 2-wire, and a 160 volt 3-wire system	80 volt 2-wire system.	125 volt 2-wire system.	Ratio of 125 volt 2-wire system, to 80 volt 2-wire system.
TOTAL COSTS.				
Insulated Wire for Power.........	3,997.80	$8,701.05	$3,860.49	.444
" " " Light.........	3,010.77	3,925.85	2,926.60	.745
" " " Dynamo and Equalizer Leads.............	1,033.21	1,033.21	785.37	.760
	$8,041.78	$13,660.11	$7,572.46	.554
TOTAL WEIGHTS.				
Insulated Wire for Power.........	10,527.89	23 827.07	10,362.40	.435
" " " Light.........	6,272.63	8,890.27	5,778.46	.650
" " " Dynamo and Equalizer Leads............	2,859.46	2,859.46	2,152.61	.753
	$19,659.98	$35,576.80	$18,293.47	.515

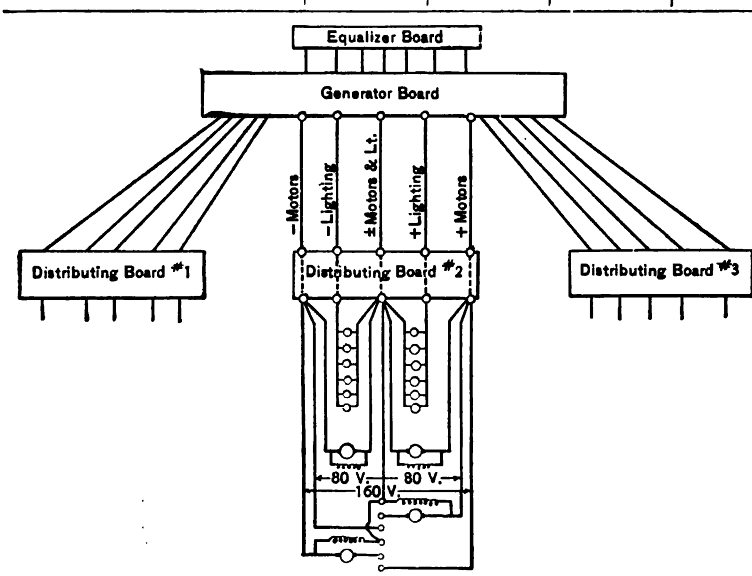


FIG. 1.

TABLE VIII.

TABLE SHOWING THE SAVING IN COST AND WEIGHT OF ENAMELED CONDUIT IN THE LIGHTING SYSTEM OF THE KEARSARGE THAT WOULD RESULT IF WIRED FOR A 125 VOLT TWO WIRE SYSTEM, INSTEAD OF AN 80 VOLT TWO WIRE SYSTEM; ASSUMING ALL WIRE TO BE IN CONDUIT.

THE 80 VOLT SYSTEM.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Size of wire in c.m.	Feet of wire used.	Diam. over insulation.	Size of conduit.		Wires per tube.	Weight of conduit per foot of wire.	Clearance.	Cost of conduit per foot of wire.	Total cost.	Total weight of conduit.
				I. P. S.	Bore.						
1	4,107	19,314	.3438	¾"	.82	2	Lbs. .56	.133	$0.040	$772.00	Lbs. 10,820
2	9,016	1,587	.4375	1"	1.02	2	.83	.145	.055	87.30	1,320
3	11,368	203	.4375	1"	1.02	2	.83	.145	.055	11.15	168
4	18,081	1,833	.4688	1¼"	1.35	2	1.12	.413	.070	128.20	2,050
5	22,799	1,838	.5000	1¼"	1.35	2	1.12	.350	.070	128.50	2,060
6	30,856	1,785	.5000	1¼"	1.35	2	1.12	.350	.070	125.00	2,000
7	38,912	1,404	.5312	1¼	1.35	2	1.12	.290	.070	98.30	1,574
8	49,077	1,030	.5625	1¼"	1.35	2	1.12	.225	.070	72.00	1,170
9	60,088	1,585	.5938	1¼"	1.35	2	1.12	.165	.070	111.00	1,774
10	75,776	942	.6250	1¼"	1.35	2	1.12	.100	.070	66.00	1,055
11	1,654,776	486	*1.3750	1½"	1.58	½	5.36	.205	.340	165.00	2,600
12	2,630,424	84	*1.6875	2"	2.06	½	7.72	.313	.480	40.30	650
	Total									$1,804.75	27,241

THE 125 VOLT SYSTEM.

	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
1	4,107	19,314	.3438	¾"	.82	2	Lbs. .56	.133	$.040	$772.00	Lbs. 10,820.0
2	4,107	1,587	.3438	¾"	.82	2	.56	.133	.040	63.48	889.0
3	4,660	203	.3500	¾"	.82	2	.56	.120	.040	8.12	117.0
4	7,400	1,833	.4000	1"	1.02	2	.83	.220	.055	101.00	1,520.0
5	9,350	1,838	.4375	1"	1.02	2	.83	.145	.055	101.15	526.0
6	12,620	1,785	.4400	1"	1.02	2	.83	.140	.055	98.00	1,480.0
7	15,950	1.404	.4480	1¼"	1.35	2	1.12	.454	.070	98.30	1,574.0
8	20,100	1,030	.4800	1¼"	1.35	2	1.12	.390	.070	72.00	1 170.0
9	24,600	1,585	.5000	1¼"	1.35	2	1.12	.350	.070	111.00	1,774.0
10	31,000	942	.5050	1¼"	1.35	2	1.12	.340	.070	66.00	1,055.0
11	678,000	486	1.3000	1½"	1.58	1	2.68	.280	.170	82.50	1,300.0
12	1,078,000	84	1.5400	2"	2 06	1	3.61	.520	.240	20.15	325.0
	Total									$1,593.70	23,550.0

*Two Cables in Multiple each of the Diameter Specified.

TABLE IX.

TABLE SHOWING THE SAVING IN COST AND WEIGHT OF ENAMELED CONDUIT IN THE POWER SYSTEM OF THE KEARSARGE THAT WOULD RESULT IF WIRED FOR A 125 VOLT TWO WIRE SYSTEM, INSTEAD OF AN 80 VOLT TWO WIRE SYSTEM; ASSUMING ALL WIRE TO BE IN CONDUIT

	(1) Size of wire in the 80 volt system in cm.	(2) Feet of wire used.	(3) Diam. over insulation.	(4) Size of conduit. I. P. S.	(5) Size of conduit. Bore.	(6) Wires per tube.	(7) Weight of conduit per foot of wire.	(8) Clearance.	(9) Cost of conduit per foot of wire	(10) Total cost.	(11) Total weight of conduit in the 80 volt system.
1	4,107	285	.3438	3/4"	.82	2	Lbs. .56	.133	$.040	$11.40	Lbs 159.5
2	9,016	922	.4375	1"	1.02	2	.83	.145	.055	50.70	765.0
3	11,368	432	.4375	1"	1.02	2	.83	.145	.070	23.80	358.0
4	18,081	160	.4688	1 1/4"	1.35	2	1.12	.413	.070	11.20	179.0
5	22,799	110	.5000	1 1/4"	1.35	2	1.12	.350	.070	7.7[illegible]	123.0
6	49,077	200	.5625	1 1/4"	1.35	2	1.12	.225	.070	14.00	224.0
7	99,064	320	.6875	1 1/2"	1.58	2	1.34	.205	.085	27.20	428.0
8	89,196	1,452	6562	1 1/2"	1.58	2	1.34	.267	.085	123.30	1.945.0
9	123,424	600	.7187	1 1/2"	1.58	2	1.34	.140	.085	51.00	804.0
10	155,648	455	.7500	1"	1.02	1	1.67	.270	.110	50.05	760.0
11	196,308	1,513	.8125	1"	1.02	1	1.67	.208	.110	166.43	2,520.0
12	240,352	1,170	.8500	1 1/4"	1.35	1	2.24	.500	.130	152.00	2,620.0
13	303,104	1,016	.9375	1 1/4"	1.35	1	2.24	.413	.130	131.30	2,270.0
14	396,256	462	.9667	1 1/4"	1.35	1	2.24	.383	.130	60.00	1.070.0
15	499,712	283	1.1250	1 1/2"	1.58	1	2.68	.455	.170	48 10	760.0
16	630,252	602	1.2500	1 1/2"	1.58	1	2 68	.330	.170	102.30	1,620.0
17	794,708	338	1.3400	1 1/2"	1.58	1	2.68	.240	.170	57.50	905.0
18	1,002,108	704	1.5200	2"	1.58	1	3.61	.560	.230	162.00	2 540.0
19	1,182,548	197	1.5750	2"	2.06	1	3.61	.485	.230	45.30	710.0
20	1,254,556	121	1.6500	2"	2.06	1	3.61	.410	.230	27.83	437.0
21	2,630,424	883	*1.6875	2"	2.06	1/2	7.22	.373	.460	406.00	6,375.0
22	3,316,930	304	†1.5600	2"	2.06	1/3	10.83	.500	.690	210.00	3,294.0
	Total									1,939.11	30,866.5

*Two Cables in Multiple each of the Diameter Specified.
†Three Cables in Multiple each of the Diameter Specified.

TABLE IX.—*Continued.*

	(12) Size of wire in the 125 volt system in cm.	(13) Feet of wire needed.	(14) Diameter of wire over insulation.	(15) Size of conduit.	(16)	(17) Wires per tube.	(18) Weight of conduit per foot of wire.	(19) Clearance.	(20) Cost of conduit per foot of wire.	(21) Total cost.	(22) Total weight of conduit in the 125 volt system.
				I. P. S.	Bore.						
1	4,107	285	.3438	¾"	.82	2	Lbs. .56	.133	$0.040	$11.40	Lbs. 159.5
2	4,107	922	.3438	¾"	.82	2	.56	.133	.040	36.88	516.5
3	4,660	432	.3550	¾"	.82	2	.56	.110	.040	17.28	242.0
4	7,400	160	.3900	1"	1.02	2	.83	.240	.055	8.80	133.0
5	9,350	110	.4375	1"	1.02	2	.83	.145	.055	6.05	91.3
6	20,100	200	.5000	1¼"	1.35	2	1.12	.350	.070	14.00	224.0
7	40,500	320	.5312	1¼"	1.35	2	1.12	.288	.070	22.40	358.0
8	36,600	1,452	.5160	1¼"	1.35	2	1.12	.318	.070	101.64	1,625.0
9	50,600	600	.5625	1¼"	1.35	2	1.12	.225	.070	42.00	672.0
10	63,800	455	.6000	1¼"	1.35	2	1.12	.150	.070	31.85	510.0
11	80,100	1,513	.6300	1½"	1.58	2	1.34	.320	.085	128.60	2,025.0
12	98,500	1,170	.6875	1½"	1.58	2	1.34	.205	.085	99.40	1,565.0
13	124,200	1,016	.7187	1½"	1.58	2	1.34	.143	.085	86.50	1,360.0
14	162,300	462	.7812	1"	1.02	1	1.67	.238	.110	50.82	770.0
15	205,000	283	.8197	1"	1.02	1	1.67	.200	.110	31.13	472.0
16	258,100	602	.9000	1¼"	1.35	1	2.24	.450	.130	78.10	1,348.0
17	325,800	338	.9400	1¼"	1.35	1	2.24	.410	.130	44.00	757.0
18	411,000	704	1.0700	1¼"	1.35	1	2.24	.280	.130	91.40	1,575.0
19	486,500	197	1.1000	1¼"	1.35	1	2.24	.250	.130	25.60	441.5
20	514,500	121	1.1800	1 "	1.58	1	2.68	.400	.170	20.27	324.0
21	1,078,000	883	1.5100	2	2.06	1	3.61	.550	.230	201.50	3,185.0
22	1,365,000	304	1.6900	2	2.06	1	3.61	.370	.230	70.00	1,098.0
	Total	. . . .								1,219.62	19,451 8

RESUME OF CONDUIT SAVINGS ON SHIPS OF THE KEARSARGE CLASS ON THE ASSUMPTION THAT ALL WIRE IS IN CONDUIT. AS ACTUALLY INSTALLED, MANY OF THE LARGER FEEDERS ARE RUN OPEN ON PORCELAIN CLEATS.

Ratio of Cost in 125 volt two wire system to 80 volt two wire system	POWER	.629
" " " " " " " " " " " " " "	LIGHTING	.884
" " " " " " " " " " " " " "	TOTAL	.752

Ratio of Weight in 125 volt two wire system to 80 volt two wire system	POWER	.630
" " " " " " " " " " " " " "	LIGHTING	.865
" " " " " " " " " " " " " "	TOTAL.	.740

sidered desirable to reduce the section of these wires, for the reason that a certain amount of mechanical strength is necessary in a wire to prevent its breaking. No fixed figure can therefore be named which will correctly represent the ratio between the aggregate weights of all the transmission lines under two different voltages. The ratio will depend very largely on the sizes of wire used. The proportional saving will be larger, the heavier the wires. In a small ship having only a lighting plant in which the No. 14 wire is used in a large proportion, the proportional saving would be smaller. The percentage of saving would therefore be different for every type of ship, and in general terms would be larger, the larger the ship. In order to determine what this saving would be, it is necessary to take each size of transmission line and calculate the particular reduction in each case due to the increase of voltage. Tables 5, 6 and 7 show a detailed calculation for the *Kearsarge* and *Kentucky* class. From this it will be seen that in these ships the ratio of the total weight of transmission lines under a 125-volt to those under an 80-volt system (two-wire in each case) is 51½%.

Table 2, column 16, gives the individual ratios of weights under the 80 and 125-volt systems for several sizes of wire used as feeders in the *Kearsarge* and *Kentucky*. This shows that the ratio varies from 42.4% to 64.5% for wires of sizes between 1,300,000 and 23,000 cm. These wires are, however, only the feeder sizes and do not include the smaller wires used as sub-mains or as branches to single outlets. An inspection of the first two lines of Table 5 will show that the double conductor and the 4,107 cm. wire form a large proportion in both cost and weight of the entire lighting system of the *Kearsarge* and *Kentucky* and on neither of these wires is there any saving due to increased voltage. The proportional saving in weight in lighting systems will therefore, on account of this small wire, always be less than in power systems. This is shown in the summary of "cost and weights," from Tables 5, 6 and 7. This summary shows the ratio of weights under a 125-volt two-wire system and an 80-volt two-wire system to be .435 in the power system, and .65 in the lighting, with the ratio .515 for the combined systems including all dynamo leads.

Conduit.—In Table 4, column 31, are shown the individual ratios of the weights of enameled conduit under the 80 and 125-

volt systems for wire sizes from 1,300,000 cm. to 23,000 cm. This shows the ratios to vary from 60% to 100%.

Tables 8 and 9 give a detailed calculation of the weight of enameled conduit for the *Kearsarge* and *Kentucky* under an 80-volt two-wire system both for the lighting system and for the power system. The results show that an increase from 80 to 125 volts results in a reduction of 13.5% in the weight of the conduit for the lighting system, and 37% in the power system. The total reduction in weight of conduit for both systems combined is 26%. As remarked under the heading of "Transmission Lines," the large amount of 4000 cm. wire common to the lighting system under each voltage materially reduces the saving in the lighting compared with that effected in the power system.

Tables 8 and 9 were calculated on the assumption that all of the wire in the ship was run in conduit. As a matter of fact, a considerable proportion of the large wire on the *Kearsarge* and *Kentucky* is run open on porcelain insulators. This practice may or may not be adhered to in the future, and it may be either expanded or contracted, so that in order to get a comparison for a fixed condition the tables were calculated upon the assumption that all wire was in conduit.

Wiring Appliances.—The weight and size of these appliances would not be affected by an increase of voltage from 80 to 125.

Switchboards.—The copper section of all bus-bars and switches in a 125-volt system could be reduced to at least 64% of the section in the 80-volt system. If reduced to 64% of the section used in the 80-volt system, the current density would remain the same in the switches and bus-bars under each system. The heating, however, would be less in the 125 than in the 80-volt system, because the radiating surface per watt lost in heat would be greater in the 125-volt system.

Costs.

Electric Machinery.—The only saving in cost in electric machinery due to an increase of voltage, would be that due to the decreased size of the commutator in the higher voltage system. Such saving in cost due to an increase from 80 to 125 volts would probably not exceed 3% in case of a generating set, and 5% in the case of an enclosed motor. Such saving would result only on the assumption that the generators and motors were accurately designed for each system of voltage. In actual practice there would be little saving in the cost of these machines, owing to the fact that it is a common practice to work up commercial standards into such shape as will come within the weight and heating limits prescribed by the specifications

Transmission Lines.—The cost of these would vary in the same general proportion as the weight under different voltage systems, although not exactly in the same proportion. Table 2, column 17 illustrates this point.

As pointed out under the subject of "weights," the saving due to an increased voltage will be less in the lighting than in the power systems. The ratios of costs are given in the summaries from Tables 5, 6 and 7. These show the saving in cost to be about 25½% in the lighting system, and 55.6% in the power system, giving a total saving in cost of insulated wire of 44.6% including dynamo leads.

Conduit.—In Table 4, column 30, Appendix V., are shown the individual ratios of costs of enameled conduit under the 80 and 125-volt systems for wire sizes from 1,300,000 to 23,000, cm. This shows that the ratios vary from 56.5% to 100%.

Tables 8 and 9 give a detailed calculation of the cost of enameled conduit for the *Kearsarge* and *Kentucky* under an 80-volt two-wire system and under a 125-volt two-wire system. The figures show that an increase from 80 to 125 volts results in a reduction of 11.6% in the cost of the conduit for the lighting system, and 37.1% in the power system. The total reduction in cost of the conduit for both systems combined is 24.8%.

Wiring Appliances.—The cost of these appliances would not be affected by any change in voltage from 80 to 125.

Switchboards.—As pointed out under the subject of "weights," the saving in copper will amount to about 36%. The saving in the total cost of the board cannot be calculated with accuracy for all conditions but is estimated at from 15 to 20%.

INCANDESCENT LAMPS.

As mentioned above, a change from 80 to 125 volts will not affect the price of incandescent lamps, but will admit of reducing the limits of variation allowed in voltage and watts per candle.

Efficiency of Operation.—No change in efficiency of operation of generators or motors is to be expected from a change from 80 to 125 volts. The efficiency of incandescent lamps is a matter of specification, as lamps for any reasonable efficiency can be easily manufactured. It was not proposed to effect any increase in the efficiency of the transmission lines by the increase from 80 to 125 volts. For lines of equal section, the efficiency of transmission would be greater under the 125-volt system, but it was deemed best to sacrifice this advantage in favor of the reduced first cost which would be effected by so apportioning the sizes of the transmission lines that they would give equal efficiency of transmission under each system. In circuits, however, which use 4000 cm. wire under the 80-volt system, as pointed out above, there will be no saving in first cost due to the adoption of the 125-volt system, but there will be a saving in the efficiency of transmission. The losses in these circuits under the 125-volt system will be to the losses under the 80-volt system as 41 is to 100.

The searchlight is the only piece of apparatus on board ship whose efficiency of operation is seriously affected by an increase of voltage. A searchlight is merely an automatic self-regulating arc lamp mounted in front of a projector. The function of the self-regulating mechanism is to keep the voltage across the arc constant. The arc voltage therefore becomes one of the most essential features of a searchlight lamp. This arc voltage is not an inflexible quantity inherent in the character of an electric arc, but it will permit of a comparatively wide variation under certain conditions. The condition having the greatest effect on the upper limit of this permissible arc voltage is the voltage of the lines supplying power to the lamp.

It might appear on first thought that the arc voltage could be raised to approximately the line voltage. In practice, however, this is not permissible. It is absolutely essential to good regulation of the lamp that the arc voltage should be considerably below the line voltage. The amount that the arc voltage is required to be below the line voltage is dependent somewhat upon the character of the self-regulating mechanism of the arc lamp.

At the present time the searchlights of the navy are adjusted for about 50 volts at the arc. The selection of this arc voltage was dependent largely upon the line voltage of 80. The arc voltage is reduced from 80 to 50 by means of a rheostat in series with the arc, so that it is apparent that a considerable portion of the energy taken from the line is used up in the rheostat.

When the proposition to increase the navy standard voltage was brought up, the question was presented as to whether a separate generator of low voltage should be provided for the operation of the searchlights, or whether the searchlights should be operated from 125-volt lines, using a rheostat in series with the lamp. Since the proposition to use a low voltage generator had only in view the saving of the energy dissipated in the rheostat, this proposition was decided against for the reason that the necessities of the service required that a searchlight should, at night, always be ready for instant service, and should always be under the immediate control of the officer of the deck.

In order that this condition might obtain when using special generators of low voltage, it would be necessary to keep these generators running on no load at all times during the night ready for service. The steam consumed by the engines of these generators when running on no load would very largely exceed the steam required to furnish the energy dissipated in the rheostat when using lines of higher potential.

Notwithstanding these considerations, investigations were undertaken to see to what limits it would be practicable to reduce the voltage of a generator and at the same time obtain an efficient operation of the searchlights. Extended experiments were made to determine the relation existing between line voltage, arc voltage, watts consumed at the arc, and total quantity of light. A description of these experiments, together with the results, is beyond the scope of this paper. It is sufficient to say that the experiments demonstrated that the line voltage could not be appreciably reduced below 80 volts without a bad effect upon the self-regulating properties of the searchlight, and a diminution of its intensity. It was demonstrated that with lines having a potential higher than 80, the arc voltage could be raised considerably above 50, and that the current could then be reduced somewhat without apparently changing the quantity of light.

It was found, however, that with equal illumination, the total energy taken from the line B was greater when the light was operated on lines of 110 and 125 volts than when operated on lines of 80 volts pressure. The increase, however, in the total energy taken from the line was proportionately less than the increase in the line voltage itself.

Operating Voltage on Board Ship—For the reasons and considerations substantially as given above, it was decided to adopt for the navy a voltage of about 125. It was recommended, however, that the generators on board ship be run normally at 123 volts. Such a reduction from 125 volts to 123 volts would have no appreciable effect upon the efficiency of operation of any motor or generator designed for 125 volts, and the recommendation was made to run the generators at this voltage on account of the incandescent lamp question. To one not well acquainted with the conditions under which the navy purchases its material this question may seem of minor importance. In the actual working of the system of supplying the service with incandescent lamps the question is, however, of considerable importance, as the navy has had great difficulty in obtaining satisfactory incandescent lamps. While lamps are commercially made at all voltages from 100 to 125, there are certain voltages between these limits at which the demand for lamps largely exceeds the supply, on account of the large number of lighting plants throughout the country which are run at these voltages. There are certain voltages, however, between these points of concentrated demand where the supply considerably exceeds the demand. In selecting a voltage for the navy, therefore, it was desired to take a voltage very near the commercial standard for generators and motors, but far enough removed from the favorite lamp voltages of large lighting plants to ensure obtaining from stock on short notice such incandescent lamps as might be required At the present time the demand for 120 and 125-volt lamps exceeds the supply, and this condition will in the future no doubt grow more pronounced From every lot of lamps made for 120 volts or for 125 volts there are always found lamps of about 123 volts. These lamps are of equally as good quality as the lamps which on calibration give the rated candle power at 125 volts and 120 volts. The voltage 123 is not, and probably in the future will not be very largely used as the lamp voltage of lighting plants, and the navy will be able to obtain such lamps quickly from stock.

Practical Working of the System.—It was only last week that an opportunity was offered to test the wisdom of the adoption of the general voltage of 125 and the specific voltage of 123 for incandescent lamp purposes A collier, the U. S. S. *Ajax*, came to the Brooklyn Navy Yard, a few days ago with her generating set worn out, broken down and of no service. The ship was due to sail in seventeen days. An 8 k.w. commercial. direct connected generating set of 125 volts rating was purchased in the open market and delivered on board ship in ten days, and the necessary number of incandescent lamps of 123 volts rating with limits of voltage from 122 to 124 were obtained in the open market and delivered within three days after the order was placed. Under the old 80-volt system, if no lamps or generating set had been in store, it would have required a considerable time to obtain them, and the ship would have been compelled to sail without a generator and using oil lights.

Conclusion.

While the adoption of the 125-volt system is a long step in the right direction, it must be clearly borne in mind that this is not sufficient in itself to ensure that all the advantages will be secured which might be derived from this circumstance. Having adopted a commercial voltage, the navy must now eliminate from its specifications all special features which are not essential to the efficient operation of its electrical apparatus on board ship. It will be only by so doing that all the possible benefits of the change will be secured.

In closing it may be remarked that the success in quickly fitting out the *Ajax* mentioned above was due quite as much to the fact that the material purchased was thoroughly commercial in other respects as to the fact that a commercial voltage had been adopted.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

ELECTRICITY IN PERMANENT SEACOAST DEFENSES.

BY MAJOR GEORGE W. GOETHALS, U. S. A.

In order to understand the history and conditions governing the installation of electrical plants for use in connection with seacoast defenses, which is the subject of this paper, a few remarks explaining the actual conditions of a military post on the coast may not be amiss. Along our seacoast there are certain harbors from which, for strategic reasons, it is desired to exclude an enemy by means of properly constructed defenses. To accomplish this object, sites are procured from which command of the approaching channels may be had, and these sites are designated as forts or posts. On these sites are scattered the guns of various calibre, either singly or, more frequently, in groups of two, three, etc., as the extent of the site and the proper command of the channel may require.

An emplacement is understood to mean that part of a battery occupied by one gun, including the platform on which the gun is mounted, its magazine, shell-rooms, storerooms, offices, etc. Two or more emplacements constitute a battery. A fort is an aggregation of batteries, together with barracks, hospitals, quarters, storehouses, etc., and such buildings as are needed for the administration, operation and care of the batteries. Therefore, "Fort Wadsworth," for instance, applies to the entire reservation on which are several batteries and the necessary buildings for the garrison. To the Corps of Engineers is entrusted the construction of the emplacements and batteries, together with the installation of such power as may be needed to light them and to operate the motors connected with the ammunition service and the maneuvering of the guns. On their completion, the works of defense are transferred to the artillery branch of the service for operation and care.

In the earlier emplacements and batteries no provision was made for using electricity, not because the desirability of its use was not considered or understood, but from a desire to mount as many guns at various localities as possible, using the very limited appropriations received from year to year for this purpose rather than for purposes not absolutely necessary. As the works for defense advanced, small available balances were expended for lighting batteries already completed, or nearly so. Where the emplacements offered available room, such plants were installed in the battery; when such was not the case, small power-houses were constructed near the batteries for the purpose, and in some cases two or more batteries were lighted from the same plant, but this was rather unusual. Such plants were necessarily small, operated in some cases by steam power, when the smoke stack or steam escapement could give no possible clue to an enemy, but in the majority of cases they were operated by a gas engine. The lamps ranged in voltage from 80 to 110; generators, switchboards, etc., were arranged to suit the particular conditions at the battery under consideration and the money available. These plants were provided with a small storage battery as a reserve, to obviate the necessity of operating the entire plant every time the lights were desired, and in their entirety were so simple that an intelligent enlisted man was able to operate them.

The number of such plants installed was comparatively small, and the subject had been regarded as rather in an experimental stage, but sufficient experience had been had to warrant a serious consideration of the subject, with a view to applying electricity in all gun batteries for furnishing light and also for supplying power to raise the projectiles of the larger calibred guns from the level of the magazines or shot-rooms to the gun platforms. The desirability of uniformity in the plants was also apparent and to secure this as far as practicable, a board of engineer officers, consisting of Major Smith S. Leach, Lieut. J. B. Cavanaugh and Lieut. R. R. Raymond, all of whom had had experience in installing and operating plants in connection with fortifications, was convened for the purpose of considering the application of electricity for furnishing light and power to the batteries, and to make such recommendations as would accomplish the desired results, and at the same time to prepare specifications which could be followed in all future work. Thus far, it must be understood, the emplacement lighting and the power for operating the ammunition hoists were alone considered, so that the conditions that such installations were designed to meet were: intermittent service, inexpert and non-continuous attendance, and exposure of the generator and switchboard apparatus to the moisture of the emplacements, since complete protection against all kinds of fire from a hostile fleet was advisable.

While centralization was considered desirable, it was not to be carried beyond the limits within which the standard voltages of all parts of the system could be maintained with a reasonable expenditure of copper, so at some posts where the batteries were considerable distances apart there might be two or more plants. The power-houses were to be in one of the batteries, if room were available, or in a bomb-proof structure built for the purpose and to be divided: for steam plants, into rooms for boilers, for engines and generators, and for accumulators; for oil engines, into rooms for engine and dynamo, for cooling tanks,if required, and for accumulators. The oil engine has given considerable trouble where used, because the engine did not accommodate itself quickly to fluctuations in the load, and on account of the impossibility of securing men in the immediate vicinity competent to take care of the engine and to make repairs in case of an accident or injury. Consequently, the steam plant was advocated.

The considerations which guided this board in the mechanical and electrical details were stated as follows:

1. The greatest probability that the plant would be ready for service at any future time, having in view simplicity of design and freedom from deterioration.
2. Uniformity of methods of operation and of methods of construction, so far as the latter involved the former.
3. Economy of operation.
4. Economy of first cost.
5. High commercial efficiency.

A vertical boiler and a generating set, consisting of a vertical high-speed engine direct-connected to a direct current, compound-wound, multipolar dynamo, the engine and dynamo resting on a common bed-plate, were recommended for all future installations. Reserves were recommended in the form of acumulators and were to be installed in all batteries, of 6-inch calibre guns or greater, their capacity to be determined by the lighting load only, without reference to the power load represented by motor-driven machinery, as the hand-operating devices were in themselves a satisfactory reserve. Reserves for the batteries to the smaller guns were to be made portable. The reserves were to be distributed so that a single accident or injury would not disable both the generator and the reserves at the same time. and also in order that any injury to outside wiring leads to the central generating plant could not disable the reserves. Under these conditions, the reserves were distributed among the various batteries, the reserve for each battery being sufficient in capacity for the lighting load of the particular battery with which it was connected.

The accumulators were arranged so that they could be divided into two equal parts for charging in parallel and discharging in series, the voltage during both charge and discharge being regulated by means of rheostats. This arrangement has many advantages for fortification work. No change is required in the normal voltage at the bus-bars, thus enabling the lights and motors to be operated while the accumulator is being charged, and in the central plant, all the accumulators may be charged at their normal rates, irrespective of their condition as to charge, without interfering with any of the motors or lights throughout the installation. The generators may be of a standard commercial type, a special winding for raising the voltage during the charging of the accumulator not being required. The danger of discharging the accumulator through the generator is reduced to a minimum, since the counter electro-motive force due to the accumulator in parallel is much below the normal voltage of the generator. The greatest disadvantage of this method of charging is its low efficiency, which, while a serious objection in commercial practice, is of less importance in fortification work. Glass jars were advocated as containers for the electrolyte, and these were to be placed on cushions made of hard rubber, so as to distribute the weight and prevent strains due to changes in temperature.

While uniformity was considered desirable in all parts of the installation, the board was of the opinion that the identical arrangement and operation of all switchboards was so very desirable that it should be insisted upon in all future constructions. The chief requirements are a dry and clean situation, high insulation and protective appliances, and the reduction of the number of manipulations required to the lowest possible limit. The board presented and recommended for adoption standard panels for generators and accumulators. A drawing of this type is appended in Figs. 1 and 2. For each installation there are required one generator panel and as many accumulator panels as there are reserves, the generator panel to be installed in the power room and the accumulator panels with the reserves. The generator panel is provided, in addition to the usual measuring instruments, feeder switches, etc., with cut-outs and fuses to protect the generator from over loads. The cut-outs are designed to open with 25% overload and the fuses to blow with 50% overload. The magnetic overload protection is in two

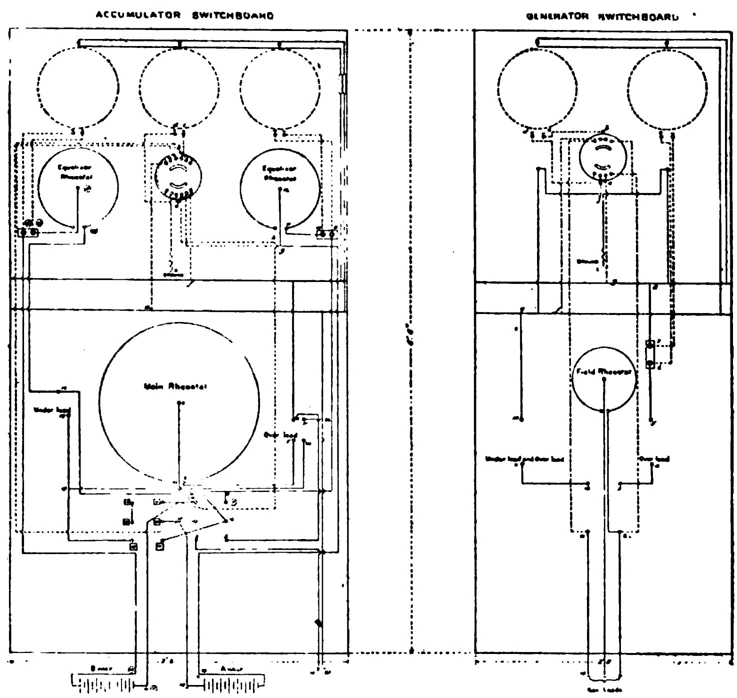


FIG. 1.

separate instruments not to be operated simultaneously, so that one is free to act during the closing of a circuit, should a short-circuit exist. One of the cut-outs is provided with an underload attachment, to protect the dynamo from the discharge of the accumulators. The accumulator panel is provided with a triple-pole, double-throw switch, making all the connections for charging or discharging the battery, as is desired, and also to protect the generator on discharge from short-circuit by breaking one pole of its leads. Both ammeters are double-reading and on charge each records the current in one-half the battery; on discharge they are in series and both record the rate of discharge. The pilot lamps are connected across the bus-bars, and will not light up when the triple-pole switch is in position "Charge," unless the generator is in operation ready to charge the accumulator.

In this system, a circuit of 110 volts is adopted for the lamps and motors, and the maximum drop in the installation of any single-gun battery is to be restricted to two volts, if practicable,

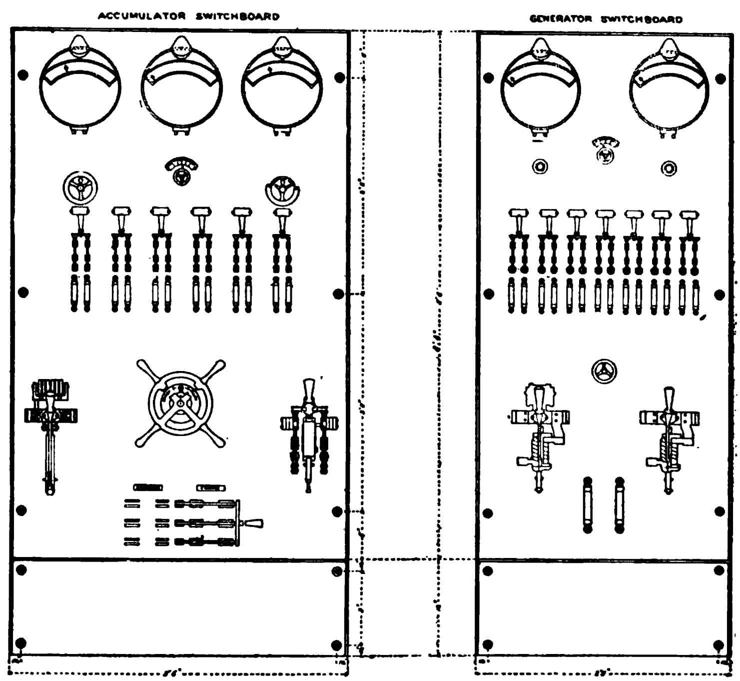


FIG. 2.

thus giving a normal voltage of 112 at the bus-bars of the accumulator panel, from which the lights and motors are supplied. In the central plant, the voltage of the generator is limited to 115 volts, if practicable, to minimize the fluctuations of voltage at the accumulator bus-bars due to variations in loads, and the conductors from the central plant to the several batteries are so proportioned as to give the same drop from the generator to each of the accumulator panels when carrying the normal loads.

Overhead wires were advocated wherever they could be obscured from the enemy's view, and for this purpose ordinary weather-proof wire with high grade insulators on stout poles was advocated. If the conditions of the ground were such that an aerial line could not be concealed from view, the cables were to be placed underground, carried in well-laid vitrified conduit at a depth sufficient to give ample cover. The specifications which resulted and which form a part of the report of this board will be found in Professional Papers No. 27, Corps of Engineers. They have been regarded as rather severe in their

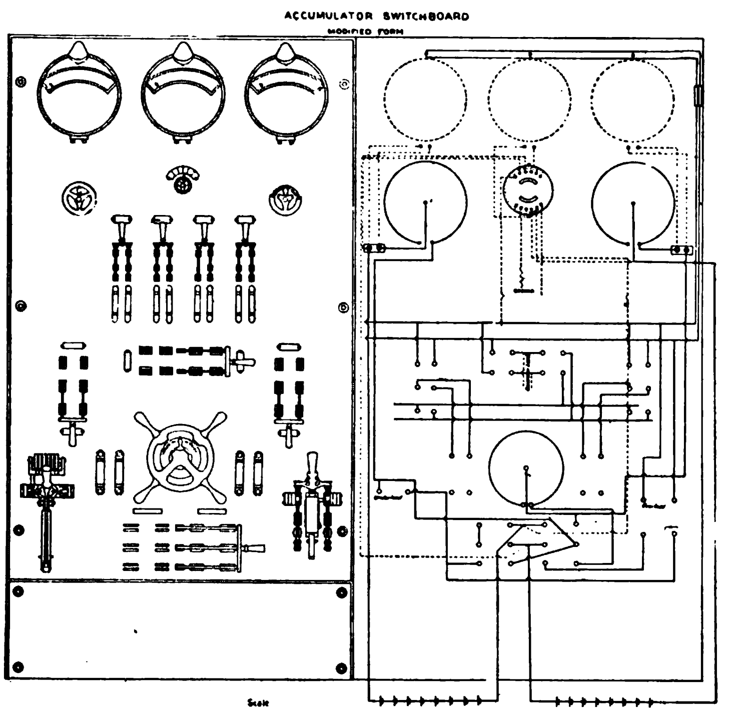


FIG. 3.

requirements as to boiler, generators, wire, etc., but in work of this character it is absolutely necessary that the best practicable types of machines be installed, for, as competition is required by law, it is better that the requirements be severe than that an inferior plant be forced for acceptance with the liabilityof failure at a most critical time.

Shortly after the issue of the report of this board and the standard specifications, combined naval and land maneuvers were undertaken at Narragansett Bay, R. I. The importance of the searchlight up to this time had not been fully appreciated, and though they were provided at the various defenses for the purpose of guarding the mine fields against a night attack, their use in connection with the batteries had received but little consideration. As a result of these maneuvers, the necessity of searchlights as an adjunct of defense was established and another factor was introduced. Future plants would have to furnish sufficient power not only for emplacement work, but also for searchlights, and this addition required an increase in the capacity of the machines to meet the greater demand. The conditions and requirements as laid down by the board remained as yet unchanged. In the two services now to be provided, the emplacement service and the searchlight service, there was this difference: electricity was absolutely necessary for the operation of the latter, while in the former it was not essential, since lanterns could supply the lights and manual labor could work the ammunition hoists and the guns

Thus far, the plants installed were used for emplacement work only, the storage batteries were charged and discharged at stated intervals and, as noted above, the service was intermittent. The plants were in the hands of the Artillery Corps, and the officers desired to avail themselves of these plants for lighting their quarters and posts, thereby insuring, by their constant use, better care. As a result, the War Department authorized the use of such plants, if of sufficient size to do this work, by the Quartermaster's Department when authorized by the Chief of Engineers, "provided that the needs of defense shall have precedence over post lighting or power supply in any case in which both uses are simultaneously desired." It was further ordered that in future, when funds permitted, the Engineer Department should construct such ducts, service wires, etc.. as might be necessary to deliver current to the buildings and to the exterior lights. The Quartermaster's Department was to wire the buildings, furnish the exterior lamps and to supply all plants used for post lighting with the necessary materials and funds for their repair and preservation. A third service was thereby imposed.

The Quartermaster's Department and the Artillery Corps desired for such lighting of posts low potential service throughout, mainly on the ground of simplicity and because of the character of labor that was to be employed in operating the plant; a centrally-located plant, due consideration being had to protection against hostile fire, accessibility for supplies, etc; that the plant be sufficiently large for doing all the work connected with the fortifications, and alternately for post and building lighting (in other words, the larger of these two services would govern the size, assuming direct current machines to be used); that the generator unit be sub-divided, thereby providing two engines and generators, so that in case of injury to either half the other would be available for the more necessary purposes; and, finally, that all wires be underground rather than overhead, in order to reduce the cost of maintenance. With these additional services, the original conditions were changed, the whole subject required consideration anew and the matter was referred by the Chief of Engineers to a board of officers of the Corps of Engineers consisting of Major Smith S. Leach, Major S. W. Roessler and the writer, to consider the entire subject from the new standpoint, including the wishes of the Quartermaster's Department and of the Artillery Corps in the matter, and to modify the requirements as originally provided for fortification purposes as the new services necessitated.

The fullest possible electrical demand at any military post will embrace, therefore:

1. Searchlight service.
2. Emplacement service.
3. Garrison service.

And the engineer officer must design his plant for these three services.

The searchlight service requires current for a number of searchlights to be used in conjunction with the batteries placed in their vicinity. The number and size of these lights for any particular post is definitely known in advance.

The fortification service requires current for lights in the various rooms of each emplacement, on each gun-platform, in the range-finding stations; current for power to work the motors for ammunition service, for traversing, elevating and depressing the guns and to operate a machine shop for minor repairs to the guns and carriages, and, finally, current for the recently adopted telautograph system connecting the range-finder stations with each other and with their respective batteries.

The garrison service requires current for lighting the grounds and buildings, including barracks, quarters, hospitals, storehouses, etc., which may be in close proximity to the batteries or at considerable distance from them, depending on the size and configuration of the reservation.

From an examination of a number of proposed projects, it is ascertained that the first and second of these services will, on the average, be of the same kilowattage or nearly so, and that the third will rarely exceed the same amount, in the majority of cases being less. The nature of the third service is not the same as the other two. The searchlights are to be operated only at night and can be operated only by electricity, and their continuous and perfect operation is a paramount exigency of the defense. Partial efficiency does not produce partial results. If the searchlights do not operate perfectly and continuously, they are of comparatively little use. The accumulator reserve alone is not satisfactory for this service, since a battery of reasonable size cannot supply the searchlights for more than eight hours, which might not suffice for making repairs. Should any mishap occur to the generating plant, it is probable that the searchlights would be put out of action. On account of these considerations, the board recommended that the generating plant, so far as the kilowattage was concerned, should be mechanically duplicated, boiler, engines and dynamos and,as a mechanical reserve is not always instantly available, in order that the searchlight might be kept in operation while the duplicate plant was being started,that the accumulator reserve should be made available for this purpose. It will be used a comparatively short time and an unusual size will not be required. The emplacement service will be required only while the guns are in action actually, or similated in drill. At such times, this is a convenience only, not a necessity, since non-electrical reserves are provided for handling ammunition and may also be arranged for lighting. An accumulator reserve is practicable for this service, since a battery of reasonable size may be made to supply the more urgent needs of the emplacements for several days, and its instantaneous availability and its ease of subdivision are advantages over a mechanical reserve. Both searchlight and emplacement services are on a non-commercial basis, and economy of operation is a consideration of comparatively little weight.

The garrison service will be required during the hours of commercial illumination and will be of constant service during peace, probably discontinued during war. Garrison service considered alone should have the same weight given to economy of operation as in commercial lighting, and the use of reserves, accumulator or mechanical, should be considered mainly from the standpoint of use. The conditions are changed when this service is connected with the other two in the same installation. Both mechanical and accumulator reserves are required for the emplacement and searchlight services, and they are available for the garrison service, their use in that service depending so far as may be upon economy of operation. Current used from an accumulator is very costly, and when the variations of load, cost of fuel and local conditions are known, a simple computation will show whether it is desirable to supply current in the hours of light load from the accumulator or to run the generator during the full hours of service.

For supplying these three services, the central power station is now adopted, its location depending on local conditions, and it must be so constructed as to be proof against hostile fire. The vertical boiler, in most cases, must give way to a more efficient type; horizontal engines must in some cases replace the vertical and they must be compound or condensing, depending on the local conditions; and the direct connection of the engine and generator, while still preferable, is not essential. The minimum capacity of the generating plant should be twice the normal demand of the searchlights, and, as stated above, should be in two equal, wholly independent parts, either or both of which may be subdivided as the local conditions indicate. Connections should be made to permit either part to supply the searchlights, giving complete mechanical duplication for this service by dispensing with the others.

Great difficulties will at times be encountered in attempting to furnish adequate garrison service at reasonable cost by using direct current. This is also true when in any particular case two forts are sufficiently near each other to warrant the consideration of one plant doing the work for both, and these difficulties are to be overcome by the introduction of alternating current for the garrison service. The condition is imposed that if alternating current be adopted for garrison service, it shall be supplied from the same plant that supplies the emplacement and searchlight services, which require direct current.

The method suggested by the Board for consideration in the accomplishment of this result is by introducing a motor generator into the garrison feeders, taking direct current from the generator and delivering alternating current to the line at 1,000 or 2,000 volts, according to the distance of the transmission. Static transformers, according to the usual commercial practice, will reduce the voltage to 110 for delivery to the lamps. The objections to this method are the cost and maintenance of an additional machine, the motor-generator, and the liability of derangement of the lighting system by irregularity or failure in its operation. The losses in the system will be those of the motor-generator, plus the line losses, plus the transformer losses at the other end.

The same result, the supplying of direct and alternating current from the same plant, may be reached by the employment of a rotary converter instead of a motor generator. This machine has but one set of coils, takes the direct current from the generator at 110 volts and delivers alternating current at 77 volts, with very slight losses. A special static transformer will be required with the proper ratio to raise the voltage to that determined upon for the line, and standard static transformers at the other end to reduce the voltage to 110 for delivery at the lamps. The losses in such a combination will be that of the converter, very small, plus the losses in the line and two static transformers, plus the losses allowed in the line. The objection to an additional machine applies here also.

A third method was investigated as far as was possible in the time at the Board's disposal. It depends upon the employment of the same machine as the second method, but it is used in a different way. The rotary converter, instead of receiving and being driven by a direct current at 110 volts and delivering alternating current at 77 volts, may itself be driven by a prime mover, in which case it becomes an A. C. D. C. generator, giving direct current from the commutator at 110 and alternating current from the collector rings at 77 volts. Constructive conditions appear to demand that these machines shall be driven at a higher rate of speed than is possible with direct connection, and if this method be adopted, belt-driving follows as a necessary consequence, but this is not considered a serious objection under the circumstances of the new installation. With an A. C. D. C. generator, a special static transformer will be required to step up and standard ones to step down, as in the second method. In this system, one machine is saved and losses will be about ten per cent. less than in the second method. The belt connection will require considerably more floor space than the engine type, and the only open question in this method is the effect of varying loads on the direct side upon the regulation of the alternating side, but as in the installations contemplated, the combined load will rarely, if ever, occur, this question for fortification purposes becomes of secondary importance.

The use of boosters where low-tension direct current is to be transmitted over a considerable distance, is worthy of consideration; not only is this true in connection with the garrison lighting, but also in charging the larger accumulators that the new conditions require. The accumulator reserves must be increased in size and be made of sufficient capacity to supply the searchlight service for *one hour* at a non-destructive rate of discharge, which the Board experimentally determined might be taken at four times the normal rate of discharge, or to supply the lighting load of the emplacement for eight hours at normal rate. The one of these conditions which called for the larger accumulator should determine the minimum size.

Recent experience in heavy mortar firing leads to the conclusion that the largest glass jars now made will be uninjured by concussion and may be safely used. So long as glass receptacles can be obtained in the market, they are to be preferred to any others, so as to facilitate the inspection of the elements. The cells should be arranged as far as possible in single tiers vertically and in single rows horizontally. While this open arrangement is of distinct value and advantage, it is not sufficiently desirable to demand the construction of a larger room, if a smaller one already built is available.

There appeared to be no good reason for changing the system on which the switchboards had been worked out. The proposed type of plant is to consist of duplicate generators for distribution to searchlights and garrison buildings, in addition to emplacements. The two generators are supposed to be equal in capacity to the normal load, with overload capacity sufficient to take care of the variations, the second generator being provided as a mechanical reserve. The generators are under no circumstances to be operated in parallel, since each being the mechanical reserve for the other, they should not be exposed to a common danger; but, with their circuits kept separate, arrangements are proposed for working them in combination in case the demand exceeds the capacity of one, each, when so working, to take care of a distinctive part of the load. What is required, therefore, is, first—so to modify the generator switchboard that it shall permit either of the generators to supply current to several of the accumulator panels, permit one to supply certain feeders, and the other to supply certain others, while making it impossible to throw them both simultaneously on to the same line; and second—to modify the accumulator panels as may be necessary to provide for such of the requirements of the garrison and searchlight services as are not met by the type previously adopted. The restriction as to parallel working applies only to such units as are duplicated for reserves; if one of these be again

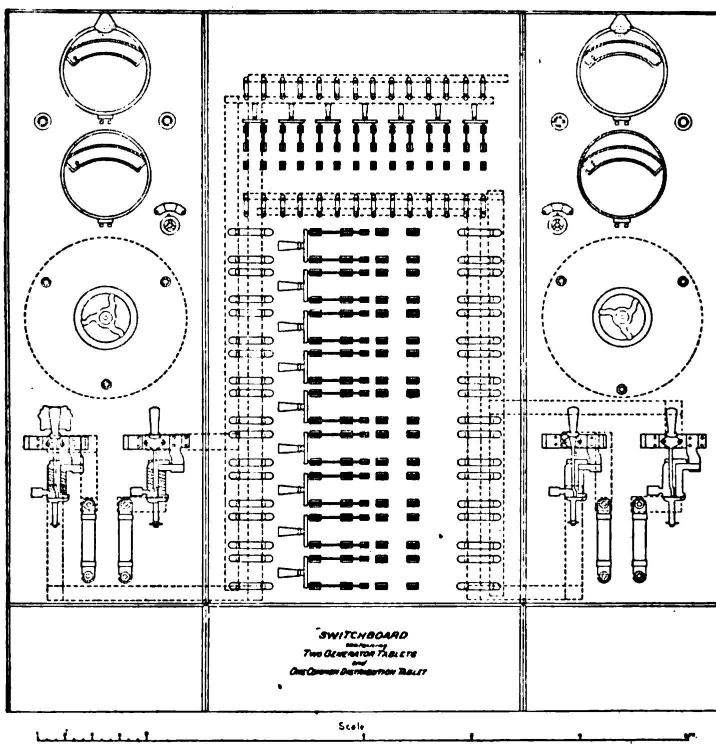


FIG. 4.

divided for economy of operation, or for other reason, the two parts may be operated in parallel on a common panel.

It is proposed to provide each half of the generating plant with its own panel, carrying the measuring and indicating instruments and safety devices required for its operation, and about one-half the feeder switches. The two panels set side by side will form the generator switchboard. The bus-bars will be placed sufficiently out of alignment, so that each pair can be extended across the other panel, connecting with the distributing switches thereon, but not with any other apparatus. The feeder switches will be double-pole, double-throw to operate on either set of busses. They should be provided at the hinge with a spring holding them firmly in the neutral position, to permit of mounting them vertically instead of horizontally, which will greatly reduce the space required and simplify the connections. A single motion will throw any feeder on to either of the generators, or from one to the other. Either generator may be operated on any circuit, or on all of them, and both may be operated together, each supplying any desired circuits, but it is

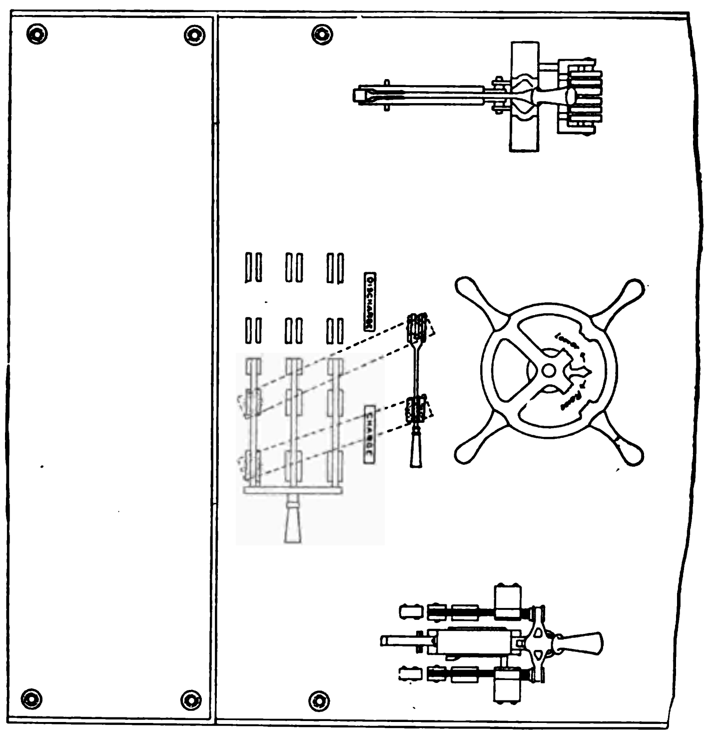


FIG. 5.

not possible to connect the two generators on the same circuit. A diagram showing two such panels is appended, Fig. 4.

Where the number of circuits to be operated is so large that the generator panels do not afford convenient space for mounting the feeder switches, the latter may be placed on a separate distribution panel, and the generator panel be reduced to the measuring instruments, a single switch connecting it with the distribution panel. This arrangement is also shown on the accompanying drawing, Fig. 5.

Two cases not covered by the type accumulator panel must be provided for. The first is to operate the searchlight from the generator while the accumulator is discharging. This may be done by using a double-throw switch for the searchlight circuit, connecting with the busses in one position, and the other with terminals branched from the generator leads at their entrance on to the board. By such an arrangement it will be found possible in many cases of long transmissions greatly to reduce the size of feeders using the accumulator exclusively for supplying lights, and throwing into line a portion of the large drop which occurs in charging accumulators and running searchlights. The second case will arise if the maximum garrison load is greater than the capacity of the generators and it is desired to put on the accumulator in parallel to take the peak. This case, it is thought, will seldom arise, and should be regarded as exceptional. The desired arrangement may be made by connecting the right-hand terminals 2 and 3 of the lower blade of the triple-pole switch through a single-pole switch conveniently placed. When the extra switch is open, the generator and accumulator cannot be put on the busses at the same time. When the extra switch is closed and the triple-pole switch thrown to the position of discharge, the generator and accumulator will be in parallel on the busses, and their joint capacity will be available. The regulation of voltages under these circumstances will require constant and expert attention, and such attention should give reasonable security from the dangers which the break 2–3 in the generator leads was designed to obviate. Fig. 3 shows the proposed modifications of the type panels.

Considerable difficulty has been experienced in the use of metallic rheostats from corrosion, overheating and mechanical derangements, and the Board suggested for the consideration of local engineer officers the advisability of substituting water rheostats for metallic ones for handling large main currents. The principal requisites of a water rheostat are non-corrosive plates, preferably carbon, with closely regulated motion to control both the distance from each other and their immersion in the liquid, which should be pure water slightly acidulated. The degree of acidulation will exercise a marked influence in the resistance of the rheostat, and may be utilized with advantage in that respect, Such a rheostat should be placed where fumes can escape easily to the air and the material for its replenishment should be kept close at hand, available for instant use, with an arrangement to operate it from the usual position at the switchboard. A water rheostat well constructed and in good working order will give closer regulation than can be obtained from metallic resistances arranged in steps.

The original specifications required for all cable laid underground, conductors of soft annealed copper 98% pure, covered by an approved insulation 5/32″ thick and protected by a lead sheating ⅛″ thick, with a saturated fibrous covering over the lead. The insulation must be sufficient to stand a potential of 3,500 volts intermittently applied, and the resistance must not be less than 1,000 megohms per mile, when tested after twenty-four hours in sea water and after one minute's electrification. With the larger size of cable that is made necessary by the extension of the service, these resistances cannot be obtained with the specified insulations and the new conditions can be more satisfactorily met by the use of the standards adopted in commercial practice, especially for battery purposes and search-light load, and the Board has so recommended. Aerial wires are also hereafter to conform to commercial practice rather than that required by the stand specifications.

In general, the use of aerial mains and branches for garrison lighting, in conformity with the prevailing practice of low potential current distribution in all but the largest cities, is regarded as feasible in cases where underground mains would be unduly expensive. Their exposure to rock splinters, shrapnel, rapid-fire and machine-gun projectiles, is not regarded as a serious objection to their use in this service, since any severed mains, being easily accessible, can be repaired if necessary. Nor is the exposure of such lines to the view of the enemy regarded as a weighty objection, except in so far as the lines and poles might disclose the position of the power-house, the location of which would otherwise remain undetected. This difficulty is easily overcome by the use of underground conduits in the immediate vicinity of the generating station. Mains for search-lights, motors and emplacement lighting should be placed in underground conduits wherever they are not concealed from view of the enemy, or where concealed aerial lines would not be reasonably well protected by intervening obstacles from shrapnel, rock splinters and machine and rapid-fire projectiles. The depth at which the conduits should be placed to secure the desired protection depends upon the nature of the ground and the configuration of its surface, and cannot, therefore, be defined in specific terms. In general, it may be said that the depths of the conduits should be greater on ground sloping downward toward the enemy than on level ground, and greater on level ground than on a surface sloping downward toward the rear. In the horizontal area within which the heavy projectiles against a fort may be supposed to fall, the depth of the mains should, if possible, be greater than the probable vertical penetration of the heaviest projectiles, but they can safely be placed at a less depth along stretches of ground against which no heavy fire is likely to be directed. Possible interruption of garrison lighting over aerial mains by storms is believed to be less likely to occur than in commercial plants in the same locality, where mains are usually of much greater length than those required on a military reservation.

In the matter of lamps, the incandescent type is used for fortification lighting, and care is taken to secure lamps that will give a suitable distribution of light in all directions, which is not done by all lamps on the market. For the lighting of the grounds, the Quartermaster's Department has adopted and installed incandescent arc lights requiring 480 watts each.

The motors used for ammunition service are to be of the completely enclosed type, practically moisture and dust proof; to conform to the adopted voltage, and must be so arranged as to be easily and quickly detached from the hoists, permitting operation by hand in case of accident; otherwise, this part of the service is in an experimental stage. Trial is being made in some of the defenses about New York with worm gearing and spur gearing, and a special type is being made by the Elicott Machine Company of Baltimore to do similar work in Boston. Absolutely safe action in raising and, more particularly, in lowering, projectiles is very essential. These motors are supplied and installed by the Engineer Department. The Ordnance Department has contracted for motors to traverse, elevate and lower the guns, and two designs are to have a trial before a standard type is finally adopted. One is being constructed by the General Electric Company and the other by the Sprague Electric Company. Descriptions of the details of motors for this service are not taken up here, for it is understood that these will be explained and discussed in other papers.

From what precedes, it is readily seen that the conditions under which the first Board worked out its problem are materially changed. Intermittent service is replaced by continuous service owing to the introduction of garrison lighting. Inexpert and non-continuous attendance, under present conditions, can no longer obtain, much as it may be desired by the Quartermaster's Department. Excessive moisture, due to condensation, is no longer to be dreaded because of the heat given by the generating plant. Simplicity of design and uniformity between the plants at the different stations, so very desirable, if not essential, since from the nature of the service army officers must be in control and changes of station from time to time seem necessary, is no longer possible, and every engineer officer in charge of fortifications must work out his own problem to suit his own local conditions, adhering to direct current throughout, if economic considerations permit, since those who are to have charge and operate the plant so desire.

Starting with the desire to light the emplacements, the application of electricity in connection with the permanent defenses has grown so rapidly and is applied for so many different purposes that it is difficult to foretell where the end will be. To the question of simple lighting is added the problem of furnishing power for the ammunition service, as a labor-saving device only, since ammunition can be supplied to the gun much more rapidly by hand than the gun service requires. Next comes the garrison service. Then we learn that motors are to be introduced for traversing, elevating and lowering the gun, machine shops to be built and operated by electricity for the use of the ordnance experts, telautograph systems to be installed by the Signal Corps for transmitting ranges and azimuths rapidly to the guns and, finally, it is learned that arrangements are to be made for firing the guns from the battery commander's station by electricity, current for all of which purposes is to be obtained from the central plant installed by the Engineer Department.

If, in the future, this advance be continued, it may not be long before even the transfer of ammunition will be made by electricity from the magazines and shot-rooms to the gun direct and the gun loaded and laid by the same means. There will then remain only the proper control in the battery commander's station to have all the work done without the aid of the enlisted man, the latter being needed only in case of a breakdown to any part of the system; in short, all that we will have to do will be to press the button, the electrical engineers and manufacturers having attended to all the rest.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

SUBMARINE CABLE TESTING IN THE SIGNAL CORPS, U. S. ARMY.

BY TOWNSEND WOLCOTT

There is much in cable testing that is old. In fact any one who for the first time reads Clark and Sabine's "Electrical Tables and Formulæ" and compares it with modern practice, will find that a great deal of information passes for new because it appears in modern books. This book was published in 1871, but it starts out with a table of dimensional formulæ, and then defines the practical units. The ohm is given as the practical unit of resistance, the volt as the unit of e. m. f., and the farad, or rather, microfarad, as the unit of capacity. The only things that would look strange in a modern book are the weber as the unit of quantity, and the metre, instead of the centimetre, as the fundamental unit of length. The book then goes on to discuss most of the questions that are considered in practical cable testing to-day.

On the other hand I do not mean to say that there is nothing new in cable testing, for if this were so there would be no call for a paper on the subject. One of the chief features of modern cable testing is the preliminary breakdown test at a high voltage. This is followed by the time-honored measurements of electrostatic capacity insulation resistance and conductor resistance, which complete the electrical testing. The armor wire is submitted to mechanical tests and a chemical test for galvanizing. These are the regular tests, and although the other materials entering into the cable may be subjected to tests, their quality may usually be determined pretty well by simple inspection.

The Signal Corps of the United States Army has charge of the greater part of the telephone and telegraph lines, including the submarine connections, owned by the army. Before the war with Spain the submarine cables belonging to the army were all short lengths connecting points on the coast and islands near the coast, but during and since the war the number of these cables has been considerably increased, while the acquisition of the Philippines by the United States has rendered necessary the laying of many cables, aggregating hundreds of miles, with some individual cables of considerable length. There have also been two moderately long cables laid in Alaska. These cables are all insulated with rubber compound, and were all manufactured within one hundred miles of New York City. In view of these facts, this paper treats only of rubber cable testing.

The greater part of the Signal Corps cable is made with a standard size of core; namely, a strand of seven No. 21 B. & S. G. copper wires, well tinned to prevent the sulphur in the rubber from attacking the copper, insulated first with pure Para rubber to the thickness of 1/64″, then with 40% compound to an outside diameter of 9/32″. This core is then taped with rubber saturated cloth tape, after which it is usually subjected to the first electrical test although this test is sometimes applied before taping. If this test is satisfactorily passed, the core is served with jute, armored and served with jute again, the outer jute being saturated with asphalt compound to protect the armor wire from the corrosive action of the sea water. The finished cable is then subjected to the second electrical test, which being satisfactorily passed the cable is accepted.

The core is usually made in lengths of approximately one mile each, which is about the greatest length that can be conveniently vulcanized, although some manufacturers can vulcanize five miles in one piece. These one-mile pieces are sometimes subjected to the first electrical test singly, and sometimes they are joined into five-mile lengths before testing. The piece of core, whether one or five miles in length, is placed in a tank of water with the ends hanging out, and there left for a number of hours at, as nearly as possible, a constant temperature. Sometimes the core is on reels, but the preferable way is to lay it loosely in the tank, doubling it back and forth upon itself, so that there is plenty of room for the water to percolate between the parts of the core thus ensuring that the core shall eventually reach the same temperature as the water.

After 24 hours' immersion the breakdown test is applied. This consists, for the standard sized core, of 5,000 volts alternating, usually with 20 to 30 cycles, though sometimes as high as 130. The object of this test is not so much to see if the general quality of the insulation is good, as to search out any accidental impurities. If the insulation be sound, this size of core cannot be perforated by 5,000, or even 10,000 volts, but in working hundreds of pounds of rubber compound it is impossible not to have an occasional speck of dirt get in, and if this speck of foreign matter be so situated as to reduce materially the virtual thickness of the insulating wall, the high voltage finds the weak spot with unerring certainty and perforates the wall at that point. It is customary to apply the high voltage for five minutes, but in every case that has come under my notice, the perforation has occurred in the first few seconds after the voltage was applied. My own opinion is that the perforation is practically instantaneous, but it takes several seconds for enough gas bubbles to collect to give a visible indication. In applying the test, one lead from the transformer is connected to the copper strand and the other lead is immersed in the water in the tank. The core so connected acts as a condenser, with the copper strand and the water as the plates. The specifications for the standard core are .4 of a microfarad per statute mile as the maximum allowed. A five-mile piece, therefore, has a capacity of two microfarads or less. Neglecting the effect of conductor resistance, this capacity at 5000 volts and 30 cycles should take a current of something less than two amperes. As a matter of fact the current is usually 1.6 amperes, which means eight kilowatts apparent energy. The power factor is, of course, very small, probably less than 1%, but is subject to considerable change on apparently slight provocation. For example, in a case where the transformer secondary was wound in four sections, the apparent energy was eight kilowatts when all the sections were connected in parallel, and twelve kilowatts when one section was used alone. This may be due, as suggested by Mr. Steinmetz, to the fact that there is a large magnetic leakage in the transformer, and that the virtual ratio of transformation is different when all the secondary current is in one section, from what it is when the secondary current is divided among the four sections. As, in the case mentioned, the instruments were in the primary circuit, the secondary voltage may have been changed without the fact being discovered. If this were the case it was not the power factor that was changed.

When a piece of core is perforated by the high voltage, the perforation at the worst is not much larger than a pin hole, and sometimes it is not discovered that the core has failed until the galvanometer test is applied. When the perforation is found the insulation immediately surrounding it is removed and the place re-insulated with rubber tape and re-vulcanized. After this, the high voltage test is applied again and in almost every instance the ordeal is successfully passed, for almost always all the weak spots are blown out during the first test.

The core, having withstood the high voltage test, is next tested for capacity. The method used is the ordinary one in which the galvanometer is used ballistically and calibrated with a known capacity. It is best to use as low a voltage as possible in this test so as to minimize the absorption effect. If the throw be taken upon closing the circuit and again upon breaking it, the effect of absorption will be to increase the first throw and to diminish the second. In my experience there is very little difference in the two throws, and the throw upon breaking the circuit is quite as likely to be greater than the throw upon making, as it is to be less. This indicates that the effect of absorption is less than that of accidental disturbing causes. It is safe to say that ordinarily the absorption effect is negligible, considering the fact that under ordinary conditions in commercial cable testing the ballistic method is not susceptible of any great accuracy. I have frequently found that a throw of over 300 scale divisions could be repeated several times without varying a single division, and that it was the same on charge and discharge.

It is likely that the capacity of rubber insulation varies somewhat with the temperature, but we have no reliable data to that effect. The thing that has the most potent influence in changing the capacity is the high voltage test. It is a well-known fact among cable manufacturers that the application of the high voltage materially increases the capacity for some time after its application. It frequently happens that a piece of core, when tested for capacity immediately after the high voltage test, has a capacity too high to pass, but if left alone for a few hours, or at most over night, it will test all right. There is, so far as I know, no intelligent theory to account for this phenomenon, but it is a stubborn fact nevertheless. The

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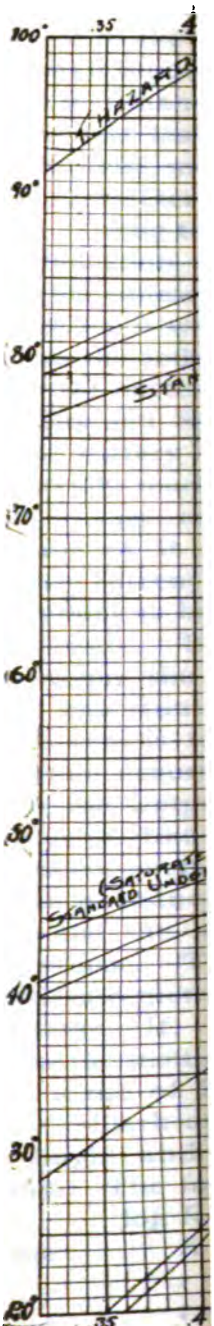

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capacity will vary considerably with different lots of what purports to be the same rubber, made up into compound as nearly alike as it is possible to make it. Even the age of the crude rubber when it is manufactured makes a difference in the capacity.

The next test is for insulation resistance. This is measured in the usual manner, by passing the leakage current through a galvanometer that has been calibrated with a known resistance. Owing to the property of dielectric absorption (so called), the insulation resistance of most dielectrics is not a definite quantity unless the manner of measuring it is specified. For this reason it was agreed in the early days of cable manufacture, to take the deflection of the galvanometer at exactly one minute after the battery key is closed. This is the method described in Clark and Sabine's book, and it has been in use ever since. If the battery be left on for an indefinite time the deflection eventually reaches a steady value, which is the measure of the true leakage current. This value may be reached in a few minutes or it may take several hours. However, this true leakage current is ignored in ordinary commercial testing, and everything is based on the galvanometer reading at the end of one minute. The high voltage test has the effect of temporarily decreasing the insulation resistance and temperature has a most important effect, and it is chiefly for this reason that so much care is taken to have the temperature uniform and to ascertain accurately its value. It is of course necessary to know the temperature in order to ascertain the quality of the conductor, but the effect of temperature upon insulation resistance is even more important than upon copper resistance.

The resistance of all insulators decreases as the temperature rises and the law of variation is more or less approximately logarithmic. That is to say, as the temperature increases by equal increments, the resistance decreases by equal ratio-decrements. If, for example, a rise of temperature of 12° reduces the insulation resistance to one-half its original value, then a rise of 24° will reduce it to one-quarter of its original value. Clark and Sabine give, on page 115, a formula deduced by Bright and Clark from experiments on Persian Gulf core (1863). The formula is,

$$\log R = \log r - t \log 0.9399$$

where R = resistance at the higher temperature;
r = resistance at the lower temperature;
t = the difference of temperature in degrees F.

The resistance is measured, as already stated, exactly one minute after the e. m. f. is applied. It is evident that the minus sign in the right-hand member is an error, for log. 0.9399 is essentially negative, and the negative sign in the formula would make it positive. Maxwell, vol. I., page 503, third edition, writes C for the constant and puts the equation in the form

$$R = r\,C^t$$

in which the error of the other formula is corrected. He gives the value of C as .8878 to .9. These values of the constant are for gutta-percha, with which we are not here concerned, but we are concerned with the general formula. Inasmuch as the law of temperature variation of the resistance is at least approximately logarithmic, it is evident that it may be plotted as a straight line on coördinate paper in which one of the coördinates is logarithmic and the other arithmetical. The annexed plate is ruled in this manner, with log 1 = 0 in the middle and extending to log $\sqrt{10}$ in one direction and log $\sqrt{.1}$ in the other. On the lines passing through the upper left hand corner the decimal point of the coefficients should be moved one place to the right. In the lower right hand corner the decimal point should be moved one place to the left. This paper is not intended so much to plot actual resistances as the ratios of resistances at different temperatures. The specifications for insulation always read that the insulation shall be such and such a figure at some standard temperature. In case the insulation is measured at any other than the standard temperature, the important thing to know is what the resistance would be at the standard temperature. If the resistance of the given kind of insulation at the standard temperature be assumed as the unit, and the resistances at other temperatures reduced to this basis, the reciprocals of these values will be the required temperature coefficients. So long as the law of temperature variation is logarithmic these coefficients also plot as a straight line on the logarithmic coördinate paper. In dealing with a new insulation it is only necessary to measure the insulation resistance at two temperatures in order to construct a table of temperature coefficients. Take the ratio of these resistances and find the point of intersection of this number taken on the logarithmic coördinate, with the difference of temperatures taken on the arithmetical coördinate; then draw a straight line through this point and the origin, extending it to the limits of the paper in both directions. In the plate the temperate coefficients of several different makes of insulation are plotted in this manner.

The simple logarithmic law is the first approximation to the true temperature law, and when accurate observations are not available it is always used and probably gives results as nearly correct as could be attained by any assumed law. When, however, a series of accurate observations is made, it is found that the temperature law contains another term. In Clark and Sabine, page 126, is given the formula

$$\log (R_t/R_{24}) = (0.06447 - 0.00017t)(24 - t)$$

where t = the temperature of observation;

R_t = the resistance at the temperature of observation:

R_{24} = the resistance at 24° Centigrade.

This formula was deduced by Willoughby Smith from experiments upon his own improved gutta-percha core. Generalizing this formula it becomes

$$\log (R_t/R_T) = (D - Ct)(T - t)$$

where R_T = the resistance at any standard temperature.

Mascart and Joubert, volume 2, page 754, give a formula credited to Foussereau Ann. de Chime et de Phys. (6) Vol. V., page 317, 1885, which applies to all known insulators. The formula is as follows:

$$\log R = A + Bt + Ct^2$$

where R is the resistance at the temperature t, and is therefore the same as R_t in the preceding formula:

A = the logarithm of the resistance at 0 Centigrade;

hence, $A = \log R_T + D\,T.$

D and B are related by the equation

$$D - C\,T = B.$$

It will thus be seen that the law expressed by the Foussereau equation is identical with that expressed by the Willoughby Smith equation. The constant, C, is usually small but not negligible. If it becomes negligible, the equation, of course, reduces to the simple logarithmic relation first given. For gutta-percha core, C is negative, but so far as my observation goes, it is positive for rubber compound cores. In two kinds of core where somewhat careful observations of temperature variation had been made, I found the formulæ best agreeing with the observations to be respectively, for Fahrenheit degrees,

(a) $\log (R_t/R_{60}) = (.00802488 + .000044619t)(60 - t)$ and

(b) $\log (R_t/R_{60}) = (\ 00845964 + .000286604t)(60 - t)$.

It will be seen that the value of the constant, C, in the second of the equations is much greater than in the first, so that not only is the temperature variation greater in the second formula, but also the departure from the simple logarithmic law. In both cases these formulæ agree much better with the observations than the simple logarithmic formula, but even in these circumstances there is a decided advantage in plotting the curves on the logarithmic paper, for when this is done the curvature is not very great in any case and it is much easier to detect an erratic observation.

Clark and Sabine give a table of temperature coefficients for Hooper core, which is a 40% rubber compound, based on the assumption that the resistance follows the simple logarithmic law and that the rise of 27° F. reduces the resistance to exactly one-half its value at the lower temperature. This is an approximation to the truth with most of the 40% compounds that I have tested, but it is not exactly true with any of which there have been accurate observations, and in the case of the compound to which the last formula applies it is widely different from the observed values. Nevertheless, these coefficients have been adopted as correct by more American manufacturers than any other one set.

One of the chief difficulties in making accurate insulation measurements is the uncertainty of the temperature. The ordinary thermometer will not at best show the temperature with any great accuracy, and supposing the thermometer to have any desired accuracy, the temperature is apt to vary in different parts of the tank. Besides all this there is no certainty, even when the water all over the tank is at the same temperature, that the core throughout is at the same temperature as the water, unless the core has been immersed for a long time and the temperature of the water has been the same for several hours. It was long ago discovered by Mr. Hockin that gutta-percha does not attain its proper resistance at any given temperature until several hours after it has attained that temperature. The same is probably true of rubber compound, in which case care in the regulation of tank temperature is all the more imperative.

However, there is much less uncertainty with core than with finished cable, so after having observed the copper resistance in a piece of core and reduced it to the standard temperature, the resistance of the same copper conductor in the finished cable will serve as a means of calculating the temperature of the cable. This in some cases is a valuable check on the observed temperature. The resistance of the conductor is measured in the usual manner with an ordinary Wheatstone bridge, and requires no further comment. The observed resistance is reduced to the standard temperature by the well known temperature coefficients for copper resistance.

Forty per cent. compound is made of 40% of pure Para gum, enough sulphur to vulcanize the rubber, and the remainder, that is the greater part of 60%, of such materials as the manufacturer thinks best. These materials are usually mineral matter, whiting, soapstone, talc or similar silicate, and metallic oxides such as those of lead and zinc. This type of compound has a temperature variation approximating that of the Hooper core; it was from one make of this type of compound that equation (*a*) was derived. There is another type of 40% compound in which the bulk of the 60% is made up of so-called rubber substitutes, which are organic substances, chiefly vulcanizing oils. This type of compound leaves very little ash when burned, showing that there is very little mineral matter in it, but the most remarkable property of it is that its temperature coefficient is approximately two for a difference of temperature of 12° F. assuming the simple logarithmic law, and is more accurately given by equation (*b*). The capacity of this compound does not appear to be increased so much by the high voltage test as that as the other compounds.

All South American rubber of good quality is called in the trade Para rubber, and as the best of it is apt to come from the regions about the waters of the upper Amazon, the best quality of rubber is called up-river Para. This rubber makes the best insulation when it is a year old before it is manufactured. The Signal Corps specifications are always for 40% of Para rubber in the compound, no African rubber or reclaimed rubber of any kind being allowed. The natives in gathering the South American rubber start with a ball of clay as a nucleus; this they coat with the sap of the rubber trees and dry it over a smoky fire. Coat after coat of sap is applied until a "biscuit" as large as can be conveniently handled is formed. These biscuits, when they arrive in this country, are of a dark color, sometimes nearly black on the outside, but when cut open are found to be of a dirty white color on the inside, and the layers separate from each other more or less readily. This rubber has a smoky smell, very much like smoked hams or bacon. but no offensive or putrid odor. African rubber, on the other hand, comes in small biscuits or nodules, is of a dark color clear through and has an extremely offensive, putrid odor, but no smoky smell. It is thus easy to tell one kind of rubber from the other before they are manufactured, but afterward they cannot be distinguished by inspection or by chemical analysis. African rubber is used to mix with Para in some of the cheaper insulated wires, but I do not know that any manufacturer uses it alone.

The tests of armor wire are chiefly mechanical; namely, tensile strength, elongation, twists in a given length, bending tests, etc. There is also a chemical test for the galvanizing. It is the practice of some users of cable in this country to armor with very large wire. The object of this is to protect the core from injury, after the manner of the shore end of a deep sea cable. Shore ends are usually made by putting an extra layer of armor over the outside of a deep sea cable, in which case there is no especial difficulty in using wire as large as is desired. When, however, heavy armor wire is used in the first layer there is sometimes considerable difficulty in laying it on over the delicate core without damaging it. For this reason the armor wire for cables of this kind is made of the softest iron procurable in the market, known in the trade as E. B. B. iron. These letters originally signified extra best bloom; that is the best quality of charcoal bloom iron, but as the iron is now made by the open-hearth basic process the letters do not mean anything in themselves,. but are simply an arbitrary designation for the purest grade of iron that can be made by that process. There is no advantage, so far as I know, other than this constructional one, in using soft iron wire for armor. On the other hand, there is a great advantage in using a high tensile steel wire in deep sea work where great strength is one of the first requisites. Moreover, in the open-hearth process, steel is obtained before iron and when iron is wanted it has to be worked longer; consequently moderately high-grade steel wire is actually cheaper than iron wire.

In view of all these facts the Signal Corps has adopted 100,000 pounds per square inch as the standard for the ultimate tensile strength of armor wire, which is obtained without difficulty in a wire which is at the same time soft and flexible. The specifications for No. 10 B. & S. G. wire are: tensile strength

814 pounds, elongation in a ten-inch sample. 10%, twists in six inches, 15. The actual tests show tensile strengths from the specified amount up to 1000 pounds and even more in some cases, elongations all the way up to 15% and twists as many as 23. The manner in which the wire breaks also shows it to be soft. When a hard wire is placed in the testing machine and tension gradually applied, the scale reading increases to a maximum, then the wire suddenly breaks with very little decrease in cross-section or necking-in at the point of rupture. When the wire is soft, the tension increases to a maximum, then the wire cripples and the scale beam drops; no further pulling will lift the beam again, but the wire goes on stretching for one or two per cent. more, and then breaks at a considerably lower tension than the maximum. There is a great deal of necking-in at the point of fracture and the broken pieces resemble positive carbon butts from an arc lamp, with a crater in the center. There is also a specification that the wire shall stand wrapping around its own diameter, but this is practically a sine qua non in wire that fills the other specifications.

The test for galvanizing is the one that has been used for a long time, both in this country and in Europe. Samples of the wire are immersed in a saturated solution of sulphate of copper and left for one minute; they are then removed, rinsed in clean water and wiped dry. This operation is performed four times, after which the wire should show no signs of a copper deposit. If the zinc coating be corroded through at any point, there will be a bright, firmly adherent deposit of copper on the exposed iron. This deposit will burnish on rubbing like good copper plating. Any copper deposited on the zinc is normally in a loose muddy condition, and is easily removed by the rinsing and wiping. Occasionally, however, there is a bright deposit on the zinc, but it can always be distinguished from the deposit on the iron by careful examination. Wire that has successfully passed the test is either the original bright zinc-color or a dark lead color inclining to black, easily distinguished from copper-color. Another indication of the quality of the galvanizing is its behavior during the twist test. Poor galvanizing will all peel off, so that the wire before it breaks is bare iron (or steel), while good galvanizing is so closely united to the wire that after rupture the pieces are still covered with zinc.

American manufacturers are to be congratulated upon the manner in which they have met the difficult requirements of the Signal Corps specifications.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

ELECTRICITY IN THE NAVY.

BY WALTER M. MC FARLAND

In discussing the applications of electricity in the navy my remarks as to specific installations will be mainly with respect to power plants and motor installations on shore, both on account of the fact that the company with which I am identified has done virtually no ship work for the navy, and because my own duties while a naval officer had little connection with such work. My experience, however, has suggested some points in connection with the use of electric apparatus on war vessels which may be of interest and possibly may afford some information.

The use of electricity in the navy was at first for purposes connected with the torpedo service, and when electric lighting became practicable its exploitation for the navy was taken up by the officers who had been devoting their attention largely to torpedoes. After some preliminary installations had been made, a board of officers investigated the conditions for lighting on war vessels with considerable care and formulated certain rules with respect to voltage, temperature limits, etc. Until very recently the general rules formulated by that board governed all installations on our naval vessels.

The standard voltage was put at 80, and in discussing the reason for the choice of this figure some time ago the Naval Inspector of Electric Lighting informed me that it was virtually determined by the requirements of the searchlights. It had been found that it was impracticable to use two of them in series, and as they required only 50 volts each, it was felt that a higher voltage than 80 for the standard would cause too much loss due to resistance of the searchlight circuit.

The limits for temperature rise were considerably lower than had been found entirely practicable for standard practice on shore, and the explanation for using these lower limits was that the temperature conditions on board ship were much more arduous than on shore, owing to the location of the dynamo room below the protective deck, which involved a very much higher initial temperature than that usually found on shore. Not to go into other details, it may be said at once that these requirements of low voltage and very low temperature limits, made the generators for naval use entirely special, with the result that unless some one concern could secure practically all the work and thus build enough of these machines to cover the development changes, naval work from a commercial standpoint would not be at all desirable. This explains why the company with which I am connected has made no effort to secure any ship work in the navy. Another large company, however, went systematically into the business of preparing to meet the demands, and as a result has installed the great bulk of electric machinery on our naval vessels. In view of the foregoing facts, it was somewhat surprising to read in the annual report of the officer having charge of electric matters in the navy a few years ago, the statement that he was in the hands of a monopoly, and that he advocated building electric machinery in the navy yards. As I told him when I once spoke to him about the matter, if the navy were satisfied to accept what everybody else found efficient and thoroughly satisfactory, there would be no trouble with respect to competition. As a matter of fact, government inspection is rigid and exacting to a degree which is not dreamed of in ordinary transactions, with the result that a machine, admirable in all respects but one, might be rejected on account of a slight excess in temperature rise in some one part. If the machines were standard in every way this would not make such a great difference, as such a trifling variation would not carry any weight with the ordinary customer; but when the machines are of such an odd voltage there is, of course, no way of selling them as they stand to any other customer, and consequently if rejected by the Government they would have only a scrap value.

In the report of the Bureau of Equipment of October, 1900, it was recommended that the navy standard of voltage be raised from 80 to 110 volts, and that special dynamos of 55 volts be employed for running searchlights. The recommendation states that one of the advantages will be to increase the field of competition, and that facilities for obtaining supplies will be improved on account of the commercial voltage being 110. This, of course, is true, but it is only carrying the change half way. What should be done is to adopt the commercial standards throughout, which would enable the apparatus installed to be of the type that is steadily manufactured in large quantities at very moderate cost and for which repair parts could readily be obtained from the storehouses of the various companies located at the principal ports.

If the claims that the dynamo-rooms of war vessels are so abnormally hot as to represent conditions very much harder than any to which dynamos on shore are subjected were accurate, there would, of course, be ample justification for the low limits of temperature rise, but,as a matter of fact, there are places on shore where the temperature conditions of the dynamo-room are worse than on naval vessels. I have in mind a case where there was some delay in testing an installation in which I was interested, and the reason given for the delay was that the engineers who were to make the test were unwilling to stay in the dynamo-room long enough during the summer season to make the test, and insisted on waiting until cold weather had set in. Anyone familiar with conditions obtaining on shore can undoubtedly cite cases in his own experience where the temperature of the dynamo-room would run up to 140° or 150° at times, which is a higher temperature than I have ever heard cited for the dynamo-rooms of naval vessels. In all these cases standard machines with the usual limits for temperature rise have given satisfaction.

There is another very decided objection to the use of non-standard apparatus due to the low limits specified for temperature rise, namely, that the machinery must inevitably be considerably heavier. This is a point which appeals to me very strongly, on account of the fact that the main machinery in naval vessels is rigidly limited in weight, and the unfortunate contractor is compelled to pay a penalty for all overweight. It always seemed to me absurd that when such vitally important things as the propelling engines for driving the ship had a weight limit put upon them, the electric equipment was either not limited or, on account of peculiarities in the requirements, was allowed to be much heavier than it might have been if made according to the best standard practice.

As you are all aware, the use of electricity on board ship for power has been of comparatively recent introduction, the first important case being the turret-turning machinery of the *Brooklyn*, which was installed about 1896. This was followed by the more elaborate installations on the *Kearsarge* and *Kentucky*, where all the turrets were turned electrically and motors were also used for ammunition hoists, boat winches, ventilating blowers, and some other purposes. While I have not personally served on board of ships with electric power apparatus I understand that it has generally given satisfaction.

Among the chief reasons which appeal to the layman as well as the engineer for the use of motors rather than steam engines is the absence of long lines of piping, which unduly heat the spaces through which they pass in hot weather, and the avoidance of the chance of leakage. It would seem that on this line of thought, the two places of all others where motors should have been installed were for the capstan and steering engines, but while there have been a few officers in the navy to advocate this, the consensus of opinion has been against it. I do not know the exact reasons assigned further than a sort of dread that the motors would be unreliable, but I presume that where the objection was made by officers familiar with electric apparatus, it was due to the fear that in both of these places there would be times when the motor would be brought up standing under load, and under such circumstances direct current motors, unless protected by external safety devices, would be burned out, and these external devices would add to the complication and chance of derangement. It is undoubtedly a fact that both the capstan and the rudder are at times subjected to conditions where the motive power would be brought up standing, so that unless safe-guards were provided there certainly would be danger of serious damage.

This last point leads me to bring up the question of the adaptability of alternating current apparatus to use on shipboard. Indeed, I may say that although I had thought about it a great deal myself, the question was asked me by a naval officer during a recent visit to one of our large battleships, why alternating current was not used. Of course the immediate answer is that the naval authorities in charge of electric apparatus still limit all electric machinery on shipboard to that operated by direct current. It seems to me, however, that the conditions on shipboard are such as to make the points which constitute the advantages of alternating over direct current apparatus of unusual weight. From the very nature of things the electric apparatus is to a considerable extent handled by men without a great deal of skill, a point to which attention has been called by the chief of the Bureau of Equipment in some of his annual reports, where he laments that the supply of trained men is not sufficient. Further than this, the induction motor, with its extreme simplicity and ability to withstand abuse and neglect, seems much better adapted to the general conditions on board ship than the more delicate direct current motor. With its ability to stand a tremendous overload and even temporary stoppage, it would answer for driving capstans and steering gear, from which the direct current motors have thus far been barred out. It would also seem admirably adapted for such work as driving the forced draught blowers for the fire-rooms, which are usually located in almost inaccessible places and where the steam engines now used to drive them, can rarely receive adequate attention when the blowers are driven at full power. Only recently I heard one of the ablest engineers in the navy comment on this very point, of the adaptability of the induction motor for this particular service. The only objection to the use of alternating current that occurs to me is the requirements in searchlights, but, as I remarked above, it is already proposed to install a special generating set, even where direct current is used, to supply the searchlights, and it will be perfectly practicable to put in a motor generating set giving direct current for searchlights, while alternating current would be used elsewhere.

While speaking about this use of motors in the department of the propelling machinery of the vessel, it seems pertinent to call attention to the fact that claims have been made for the adaptability of motors to drive the propelling machinery which seem ill-advised. These claims are based largely on the admitted high steam consumption of many of the steam auxiliaries against which a much lower steam consumption could be figured where these same auxiliaries were driven by motors. The fact must not be overlooked that on war vessels, as at present designed, the dynamo-room is at a considerable distance from the boilers, involving long lines of steam and exhaust piping, while the steam auxiliaries in engine and fire-rooms are so situated that the steam and exhaust connections to them are very short. Further than this, while the steam consumption of these auxiliaries, considered alone, is undoubtedly very high, the fact was overlooked by those advocating the use of motors, and who were not familiar with the details of propelling machinery, that provision has for some years been made for turning the exhaust from these auxiliaries either into the receivers of the main engine, or into the feed water heater. In either case the steam expenditure was enormously reduced and the heat in the steam utilized to the fullest extent possible, under which circumstances their steam consumption per horse-power would be lower than that with the motor drive. It is sufficient to note that where the steam is turned into the receiver, the cylinders of the auxiliary become in effect an extension of one of the cylinders of the main engine and, consequently, the steam consumption becomes the same as that of the main engine, which even at reduced power is considerably below that of the small engines driving the dynamos.

There are enough places on board ship where motors may be used with great advantage, convenience and economy to make it unnecessary to urge their installation in places where they could not hope to give the satisfaction that is given by the steam auxiliaries, with respect to speed regulation, economy and weight.

My attention was recently called by a prominent officer of the navy department to a proposition made for sub-dividing the dynamo-room and having two, located in different parts of the ship, with the object of preventing the complete disablement of such vitally important parts as the turrets and ammunition hoists, in the event of a shell getting into the one dynamo-room as now arranged. I was very much surprised to learn that objection had been made to this on the score of complication, and I cited the case of the Explotadora system in Mexico, where there are seven a. c. generating stations scattered along the mountain side at distances of from ten to twenty miles from the receiving station, where the current from the different stations is brought together on the same bus-bars and transmitted to the city of Mexico. It seems to me that this proposition is an eminently sound one, and while there would, of course, be a slight increase of complication, it would be as nothing compared with the increased safety against total disablement.

Installations on Shore.—Naval requirements for electric machinery on shore are practically for standard apparatus, so that here the criticisms which I have made do not apply. Each bureau decides on the apparatus which it deems best for its own purposes, and all who make apparatus of the class wanted have an opportunity to bid. This brings up the natural inquiry from those not familiar with naval matters as to why there should not be a central plant for each navy yard, supplying all the current needed for use in the yard, whether for lighting or power. The reason why this has not obtained is, primarily, that all of our large navy yards have been established for some time, and they were at first entirely steam-driven plants. As the yards are of large area, with the different shops scattered, it was, of course, the best practice at the time they were laid out to have individual power plants for each set of shops. Under the existing system of appropriations some bureaus were able to install an electric drive earlier than others, and in this way we have the present condition, where in a single navy yard there may be several power plants, each for its own particular set of shops. I think there is little doubt that in any new yards that are established the tools will be entirely motor-driven and the current will be derived from one or more power plants. I say one or more, because it would depend on the location of the yard. Where a yard is isolated, as is the case at Mare Island, near San Francisco, or at the proposed station in the Philippines, it would seem unsafe to put the whole power plant in one locality, for the reason that any damage such as that caused by a fire, earthquake, or other disaster, would lay up the whole yard. Where a navy yard is near a large city or any establishment having a large power plant, arrangements could probably be made, in case of damage to the yard's power plant, to rent current for a time.

Most of the apparatus installed in the navy yards is of the direct current type, probably because the earlier installations were made before the induction motor had become so prominent as it has in recent years, and consequently as installations were increased the direct current was necessarily adhered to. In some recent plants, however, while direct current is used, the installation has been on the three-wire system from a single generator on the Dobrowolski system. This has enabled larger and fewer units to be used, with resulting satisfaction.

In two very interesting plants alternating current has been used, with induction motors of course, the first at the ordnance proving grounds and powder factory, at Indian Head, Md., and the other at the steam engineering plant at the Brooklyn Navy Yard.

At Indian Head the induction motors commended themselves on account of their simplicity and absolute immunity from sparking, but as it was desired to have a short line of railway with an electric locomotive for hauling guns from the dock to the proving range, and for other purposes, some direct current was also necessary and the generators installed are of the A. C., D. C. type. The railway is operated on what is known as the "button system," or electro-magnetic traction system. It was undesirable to have overhead wires, and an underground trolley would also have been objectionable, while the button system answers the requirements of the case admirably. This plant has been installed about three years and has given great satisfaction.

The plant at the Brooklyn Navy Yard has been only recently put in operation, although the contract for it was made in 1899, the delay being due to the fact that the power house was not completed until last fall. In this case the Bureau of Steam Engineering detailed an officer who visited important manufacturing establishments all over the country to ascertain the general opinion as to the best type of apparatus to install. He also visited various electrical manufacturing concerns to discuss with their engineers the merits of the different systems. As a result of his report, it was decided to use alternating current generators with induction motors for the tools, and the plant is an excellent illustration of the most advanced practice in the powering of a modern engine-building plant. Just about the time when this contract was placed, the large ship and engine-building establishment at Camden, N. J., known as the New York Shipbuilding Company, was also considering the question of electric driving, and after going into the matter very carefully under the guidance of a prominent electrical engineer, it also decided for alternating current with induction motors. In this plant there is an unusually large number of cranes, and as the crane builders generally charge a considerably higher price for alternating current cranes, it was decided to drive these by direct current. As a result, the two 500 k.w. generators are of the A. C., D. C. type, like the much smaller ones at Indian Head.

A comparatively new field for the application of electricity in the navy yard is in the dry-dock machinery, and in all the contracts made since the early part of 1899, it has been arranged that the pumps are to be driven by motors and that the capstans and winches around the docks are also to be electrically driven. Power drive for the latter would be practically impossible except by the use of electricity. Thus far all of these installations have been by direct current, but I believe there is little doubt that as the naval authorities who have charge of these matters become more familiar with the advantages of alternating current apparatus, this form will be used, because it seems much better adapted to the circumstances of the case than direct current.

Naval work on shore where electricity can be applied is largely in the nature of manufacturing and repair establishments, and consequently we would expect that the equipment which commercial manufacturers find to give them the best results would be adopted for the navy. This is, indeed, the case, and just as no large manufacturing establishment under private auspices now thinks of using anything but the electric drive for its tools, so the same thing is true of naval establishments.

With respect to the application of electricity on shipboard, the circumstances are such as to give a very promising field and my opinion is that if alternating current were adopted there would be a much greater number of motors installed than at present.

A paper presented at the 166th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

ELECTRICITY IN THE SIGNAL CORPS.

BY LIEUT. COL. SAMUEL REBER.

The application of electricity to the art of war has kept abreast with its development in the commercial world. The engineering conditions under which it is applied are practically the same as in ordinary life, but are prosecuted under conditions which, of necessity, must be more exacting and difficult. Efficiency and certainty of operation outweigh in the problem of design the cost of installation and economy of operation. Many ingenious means and methods of the application of electricity to the military service have been devised from time to time, but a large number proved of little value, as they have been either too complicated or too delicate. No device or apparatus which cannot survive lack of attention and skilled supervision, exposure to weather, rough handling in transportation, or the effect of the blast of heavy guns, will prove of value at the critical moment of its use at the time of actual battle.

Unfortunately for efficiency, the technical corps of an army is a very small proportion of its total strength, and the pay of the enlisted men is not sufficient to prove an inducement to men skilled in the use of electricity, who are much better paid for the same work in civil life, to enlist in our service. One of the greatest limitations of its development in the service has been lack of appreciation by Congress of its importance, and the consequent lack of necessary appropriations.

The signal corps of the army is charged with the construction, repair and operation of military telegraph lines, and the duty of collecting and transmitting information for the army, by telegraph or otherwise.

While the importance and value of rapid means of communication in the commercial world have been demonstrated by the experience of over one-half a century, and the enormous amounts of capital invested in the telegraph, telephone, and cable, such means of communication are absolutely essential to success in modern war, where time is one of the most important of controlling factors. Electricity is the most potent agent in our control to effect such a saving of time.

The service of communication in the Signal Corps is divided into field and fortress work. For field work the telegraph, telephone and cable are now employed, and possibly in the future wireless telegraphy will be, when more positive results are obtained in working overland.

In the American armies, both of the north and the south, in the war of 1861 to 1865, was the first application of the telegraph under war conditions. The advantages and results proved so satisfactory, that nearly all of the foreign powers have followed our methods, and the present modern system of field communication is but an amplification of the results obtained in that war, taking advantage of the engineering progress and the recent developments in the arts of telegraphy, telephony and cable working.

A complete chain of communication must extend in an unbroken line from the extreme outposts in contact with the enemy, back to the capital at Washington. This chain of communication is divided into three parts: permanent, semi-permanent, and temporary, or flying lines. The permanent lines are usually those of the existing commercial telegraph and cable companies, and are, ordinarily, outside of the active zone of operations, and if taken possession of by the military forces, are operated under the methods of commercial practice. Semi-permanent lines are used to connect the principal base or depot of supplies on the edge of the zone of operations with the field base within it, and in this service the lines are constructed by using iron telegraph poles with cross-arms. Field or flying telegraph lines are used in the zone of active operations, and connect the field base with general headquarters and the general headquarters with all the principal sub-divisions of the army, even to the extreme outposts. A detailed description of the manner of erecting these lines will be given a little later

For working the permanent and semi-permanent lines the ordinary closed circuit system of Morse, with the usual instruments, is employed. The invention of the telephone added a valuable adjunct, and especially so for flying lines, whose construction is at times most hasty, and whose insulation is so low that ordinary Morse working is often impossible. As troops advance it is frequently necessary to lay bare wire on the ground, hang it on trees, or even leave it in marshy ground, so that the circuit will be absolutely grounded for ordinary telegraph working. Under such conditions the buzzer has proved most successful, the delicacy of the telephone receiver making its use practicable. The buzzer is simply a coil of low resistance and high self-induction in series with a circuit breaker, a telegraph key and battery. On opening the circuit the discharge of the coil goes to line and, owing to the high self-induction and consequent comparatively high e. m. f., enough current reaches the telephone receiver at the other end of the line to give audible signals.

The telephones used in fortress service are modifications in design alone of the standard commercial types. Portability, simplicity, and mechanical strength are the essential features covering the design of all field telegraph and telephone apparatus, and will be illustrated in the description of the following special apparatus that has been designed by various officers of the Signal Corps to cover field conditions.

While great progress has recently been made in the application of wireless telegraphy for the exchange of messages over water, its value for land communication, except in very exceptional cases, is quite problematical. The distances which as yet have been covered in land working, are of comparatively short length, and its certainty of operation without interference is as yet unproved. The existing methods of communication have proved sufficient, especially as a field line, under ordinary circumstances, may be erected at the rate of from one to three miles an hour, depending upon the character of the ground. Whenever absolute syntonic working is achieved and interference by the enemy can be prevented, wireless telegraphy may have a valuable field on land in the future, but at the present outlook, it is much more suited to the operations afloat than ashore.

Before the outbreak of the war with Spain the cable operations of the Signal Corps were confined to maintaining the limited systems of cable communication between the various forts in the harbors of this country When the expedition arrived off the coast of Cuba, near Santiago, the French cable leading to that point was cut, and, to avoid delicate questions of neutrality the first war cable ever laid by our government was run from Guantanamo to Siboney by the Signal Corps, and connected with the military line to Shafter's headquarters, so that the White House was only twenty minutes in time away from the firing line in an enemy's country.

As soon as the Philippine Islands were occupied, inter-island communication became so essential that the Signal Corps was called upon to take up the question of deep-sea cable engineering. Apart from its value as a means of communication, the establishment of the Philippine cable system gave the American manufacturers an opportunity to engage in the production of deep-sea cable, and has resulted in the establishment of such plants as will in future enable us to obtain at home this most important war material, and not place the government at the mercy of foreign producers, whose friendly interest cannot always be counted upon. It is interesting to note in this connection that the American manufacturers say they are prepared to make and lay the proposed American-Pacific cable, the project for whose construction is at present pending in Congress. The importance of the early consummation of this project, both for strategic and commercial reasons, gives rise to the hope that it will be settled at this session, whether laid under government supervision, or as a private enterprise.

The Type C apparatus, Figs. 1 and 2, is designed to use the buzzer principle, and is contained in a hardwood box of cubical form, 8½ inches on the edge, and weighs about eight pounds. The working parts are fastened to the front, which is hinged, and when in use lowered on a table The back is also hinged to give access to the cells of dry battery that are contained in the body of the box The transmitter and receiver fit in the space above the battery. A condenser of one-third microfarad capacity is placed under the board on which the working parts are mounted, and is connected to binding posts 2 and 3. The buzzer coils E are simply two coils wound in parallel, eight ohms each, one side of the windings of each coil being grounded on the frame at 8, and the other sides connected at 9. The circuit-breaker consists of a thin iron reed, fastened by a screw to the core of the left-hand coil, and supported in the

Fig. 1.

middle by a brass rod, which passes through a vertical standard at 12, and is capable of being adjusted by the two antagonistic lock nuts. There is a particular note for working, best adapted to each condition of the line, and this note is obtained by changing the tension of the reed and altering the air gap between the free end of the reed and the core of the right-hand coil. The two contact points at 10 are of platinum, and the pressure of the stationary contact point is regulated by an adjusting screw, which also assists in changing the pitch of the note given by the buzzer. The circuits are shown in Fig. 2. The receiver is at-

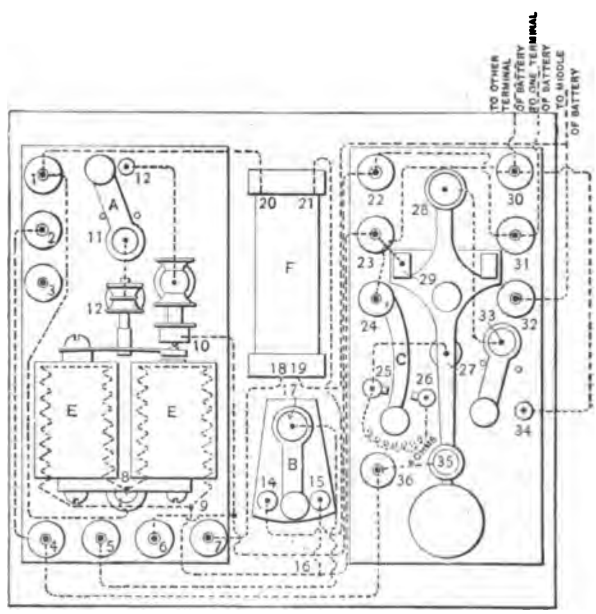

FIG. 2.

tached to 4 and 5, and the transmitter to 6 and 7. The switch A short-circuits the contact breaker; the switch B changes the connection from telegraph to telephone; switch C is used in changing from buzzer to ordinary Morse; switch D, when closed, puts one-half battery on the Morse circuit; coil F is an ordinary telephone induction coil. When in use for sending buzzer Morse A, is open, B is on 15, C on 25, and D open. For ordinary Morse A, is on 12, B on 15, C on 26, and D on 34. For telephoning, A is either open or closed, B on 14, C on 25 or 26, and D open. The battery, which consists of six dry cells, is connected with

30 and 31, the middle of battery with 32. The sending key is the ordinary telegraph key with an additional front contact 35, which is so adjusted that it will barely break when the key is up. When sending buzzer Morse the current passes through battery, key and coils to contact breaker and thence back to battery. Each time the current is broken by vibrations of the reed at the contact points 10, the coils discharge at 8 and 9, and go through 16, and as the key is down to 23 and 29, through key to 35 and 36 and 4 to 2 and line, 1 being earthed In receiving buzzer Morse the current passes through 2 to 4, through telephone receiver to 5, and back through 15 and 17 and coils to earth. In sending ordinary Morse the current

FIG. 3.

is passing steadily from the battery to 30 and 34, through D to 33, to 28, through back contact of key to 29, and through coils as above, no buzz occurring as the vibrator is short-circuited. When the key is depressed the coils discharge, due to the break occurring at 28. This discharge goes to line as above, and gives a note in the receiver at the distant end. As the key is depressed, contact is made at 27, and current now passes from battery through 30 and 24, through C to 26, and through the resistance to 25 and 27, through the key to 29, and through the coils as above. The current is consequently weaker than before, and when the break occurs on the up-stroke the sound

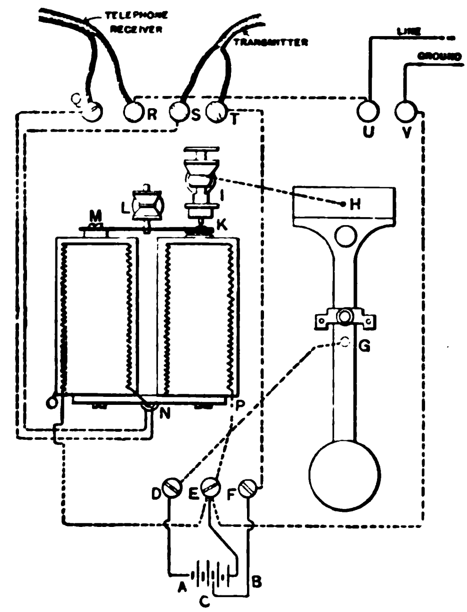
TELEPHONE RECEIVER
TRANSMITTER
LINE
GROUND
Q
R
S
T
U
V
I
H
L
M
K
G
N
P
D
E
F
A
B
C

FIG. 4.

FIG. 5.

in the distant receiver is less than on the down-stroke; thus giving the same effect as with an ordinary sounder. The tele phone circuits are the same as in an ordinary telephone. The condenser is used when it is desired to cut the kit in on a telegraph line, or for phonoplex work.

Type D, which is shown in Fig. 3, is a simplification of type C, and has proved invaluable in field service. It is enclosed in a leather case with straps, 6½x7½x4½ inches, and weighs about

FIG. 6.

seven pounds. It is used for buzzer work and telephoning, and the circuits are indicated in Fig. 4.

The field telephone kit, as shown in Fig. 5, is contained in a strong wooden box 11x7x7 inches, weighing 12 pounds. This kit is supplied with a magneto call, combined receiver and transmitter, and dry battery. The combined receiver and transmitter consists of a transmitter of the Ericson type, and watch-case receiver, which are connected by steel rods for strength; these steel rods form part of the circuit, and are partially covered by a wooden handle, containing a compression switch for controlling the battery circuit of the transmitter. which is supplied by two dry cells.

The cut-in telephone, as shown in Fig. 6, is used for cutting in on ordinary telegraph lines to talk between repair parties without interrupting telegraphic communication, and for outpost service in the vicinity of a telegraph line. The wiring of the kit is shown in Fig. 7. It is contained in a strong wooden box, 6¾x5½x9¼ inches, weighing approximately eight pounds, and consists of a watch-case receiver R, of low resistance, a serrated metal plate P on the side of the box, a metal stylus S, coil C, which is wound to four ohms, the core consisting of soft iron wires projecting a couple of inches beyond the end, telephone transmitter T, battery switch B, four dry cells B-A, and

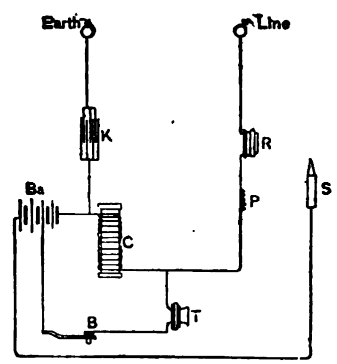

Fig.

a one-microfarad condenser. When not in use the watch-case receiver, stylus and the mouth-piece of the transmitter are fastened on the inside of the door. When the stylus is scraped on the serrated plate the coil is charged, and discharges to line, giving a harsh rattling note, which serves as a call in the distant receiver, and when answered, the transmitter is used by closing the switch in the battery circuit. In case the two parties who are communicating with each other are on opposite sides of a telegraph station, the instrument at the station is bridged by a condenser.

The field telephone switchboard, as shown in Fig. 8, is for ten lines, and is contained in a stout box, 15x9½x14½ inches, and weighs 34 pounds. The line binding posts are on top of the box and protected by a hinged cover. The front and back are both hinged for easy access to the working parts, which are mounted on a hard-rubber panel, countersunk in the front board, the bottom of which is recessed to hold the combined receiver and transmitter. The wiring of the board is shown in Fig. 9. The drops are of the high-resistance tubular type, permanently bridged across the line. The first row of keys are ringing keys, and the next three rows are cross-connecting keys, while the three keys below the panel are listening keys, each being connected to a line of cross-connecting keys. Turning down any two cross-connecting keys in any row connects these two lines. The listening key is bridged across the connecting strips in each

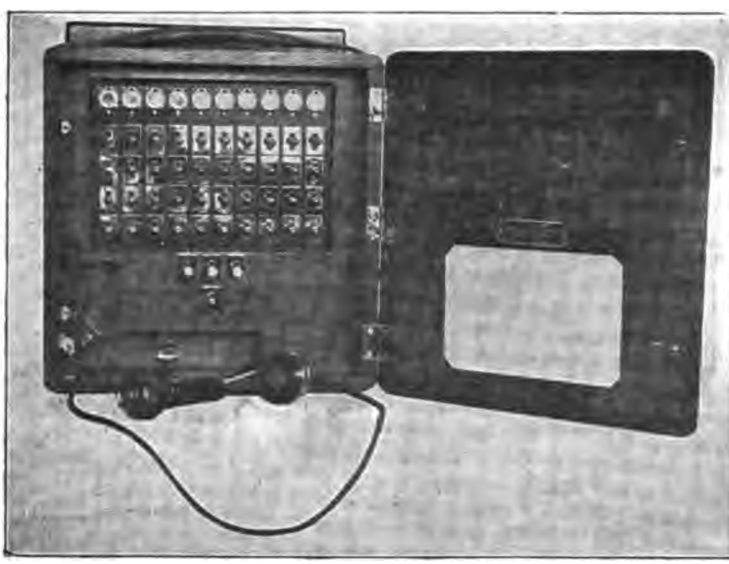

FIG. 8.

row. The board is supplied with a magneto-generator, and all the drops have the usual night bell attachment. Four dry cells are used, two each in series multiple. A strip of wood, faced with felt, is fastened to the rear face of the front door, in such a position as to keep the shutters of the drops from moving while the switchboard is being transported. This switchboard is very strongly and compactly made, so as to stand rough usage in the field without damage.

For small central stations, up to about 40 lines, a compact type of switchboard is shown in Fig. 10. The 20-line board is 25x9¼x12 inches, and the 40-line is 25x9¼x20½ inches. All the working parts, except the magneto, which is fastened to the back of the board, are mounted on a hard-rubber panel inserted in the front of the board, which is hinged to the back-board, at the bottom of which, protected by a hinged cover, are the line terminals. The whole board is designed so that all parts will be easy of access, and its wiring is that of the usual practice, the operator's set being a combined receiver and transmitter.

The field searchlight section consists of a generator truck, Fig. 11, and a projector truck, Fig. 12. The boiler is the Cap

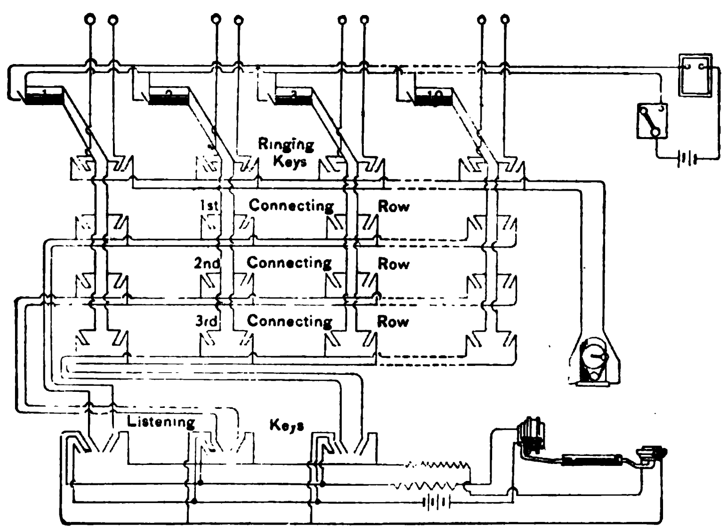

FIG. 9.

coil water-tube boiler, and steams equally well with coal or wood. The engine is a 3″x3″ direct-connected to a G. E. M. P. 6-2.5–800, 80-volt generator. In the photograph these are shown encased in Russia iron to protect them from the weather, and are situated just behind the water tank in front, the capacity of which is sufficient for a two-hours' run. Above the generator is a cylindrical oil tank. On the shelf between the boiler and engine is located the field rheostat, which is enclosed in a weather-proof covering, and a space is left on the shelf for a voltmeter and ammeter when the generator is in service. This truck can be easily hauled by two horses, and weighs, with fuel and water for a two hours' run, 5,300 pounds. The projector, which is the 18-inch type of the General Electric Company, with both hand and automatic control, is mounted on the rear platform of the projector truck, which weighs 3,000 pounds. Spring-supported in the center of the truck is a box to carry the door and reflector, while the locker under the seat has compartments for 125 carbons, the voltmeter and ammeter and tools. Underneath the platform of the truck is the cable reel, which is fitted with contact rings, which are protected from the weather by brass housing. The cable itself is in one length of 1000 feet, twin conductor, 0.77 ohms resistance, this resistance being sufficient to give the proper drop from the generator to the arc. The projector can be trained 360° in azimuth, and from 30°

Fig. 10.

below to 70° above the horizontal. The projector is furnished with a radial shutter for signaling purposes, which slips as a hood over the door. This shutter consists of 16 over-lapping radial leaves, each one pivoted at its inner end in the central hub, and at the outer end in the frame. The inner ends are so connected in the hub that by partially revolving it by a lever from the side, the edges of the shutter are turned in the direction of the beam. The hub is spring-controlled, and the tension of the spring keeps the leaves of the shutter normally closed. By opening and closing the shutter, short and long flashes of light, corresponding to the dots and dashes of the Morse code, can be sent and signals exchanged at night for long distances.

Messages can be frequently exchanged from distant stations, which are not intervisible, by throwing the beam on the clouds.

The material for constructing and operating the flying telegraph line is carried in the field telegraph train, which consists

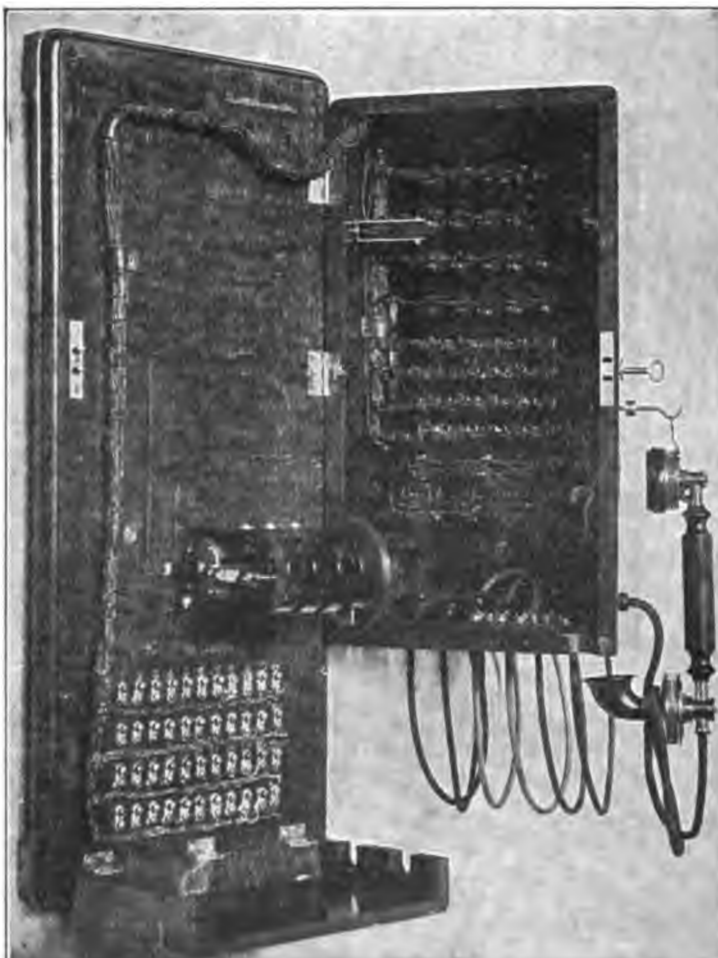

FIG. 10 A.

of three telegraph sections and a field searchlight section, which has been described above. Each telegraph section contains material for the erection of from 15 to 17 miles of line, and consists of a wire wagon and a lance truck. The lance truck contains 500 lances, 20 lance butts, hard-rubber insulators, and the necessary digging bars and tools. The wire wagon contains 20 miles of wire, both bare and insulated, reels, line construction tools etc., several sets of instruments and stationery necessary for operating an office. Attached to the telegraph train is the battery wagon, which is equipped with a sufficient number of cells of the Eagle, Edison-LeLand, or storage type, to operate the lines. Battery is used at one end of the field lines alone. This wagon also carries the various types of field apparatus, serving as a central office for the system that is erected by the train.

FIG. 11.

The lances are of well-seasoned cypress or spruce, 14 feet long, 2 inches at the butt, and 1½ inches at the top, the lower end being pointed. The lance is tipped with a malleable iron ferrule with a screw socket for fastening the insulator, which is of hard-rubber or gutta-percha, moulded on a standard that screws into the ferrule. The insulators are of two kinds: slot and "pig-tail." In the slot insulator, the top is channeled for a depth of one-half inch to allow the wire to slip through it, and is supplied with a pin to prevent the wire from rising out of the slot after being placed therein. In the "pig-tail" insulator, an additional iron piece in the shape of an S is moulded in the top. This "pig-tail" is used to keep the tension on the line by tying the wire around it. In constructing the line approximately every third insulator is of the "pig-tail" type.

In constructing the field line, after a preliminary reconnaissance has been made, the location of the lances is fixed by pins marking their position, the distance between the lances being from 50 to 60 yards. A working party equipped with crowbars sinks the holes, from 2 to 2½ feet in depth, according to the nature of the soil, and following this working party is the lance truck, which distributes the lances along the ground. The wire is then paid out from the wire wagon, following the lance line.

FIG. 13.

The wire is slipped into the slot insulators or tied to the "pig-tail" insulators, the lances then raised and inserted in the holes and tamped. When it is necessary to cross roads the lances are lengthened by a butt joint, which is of the same material as the lance, 10 feet long and 2½ inches in diameter, to which the lance is fastened by suitable clamps. In favorable ground a speed of three miles an hour has been obtained in erecting a line in actual service. As the advance continues the field telegraph train is followed by permanent construction parties, which erect either permanent or semi-permanent lines, depending upon the nature of the communication required. The maintenance of lines, especially when operating in an enemy's country, is the most difficult, trying and dangerous operation connected with field communication.

For fortress service the most important system of communication is that for fire-control. Fire control is the system by which the officer known as fire-control commander directs the fire of the separate batteries under his command. The combination of two or more fire-control commands constitutes a fortress. The chain of communication is as follows: The fortress commander is connected with each fire-control command, each fire-control command with the position-finding stations of the batteries constituting it, and each battery position-finding station with the guns of the battery. The unit in fire-control is a battery, which contains from two to five guns, varying in type from the 12-inch to the small rapid-fire guns for the defense of the mine field. Each battery has a position-finding station, from which the range and azimuth of the targets are obtained. There are two general systems for determining this: the vertical and horizontal base systems. In the vertical base system the range and azimuth are obtained by direct observation with a range-finder, and in the horizontal base system by simultaneous observations from the two ends of the base line, the observed azimuths being communicated to a plotting room, where they are laid down on a specially prepared map, and the range and azimuth of the target determined. After this data has been obtained, by either system, it must be communicated from the battery command station to the guns, as well as certain tactical data as to the kind of shot or shell to be used, etc. As yet, neither our own, nor any of the foreign governments has reached a completely satisfactory solution of this problem. A number of devices have been tried: the telegraph is too slow, and requires skilled operators; the various systems of step-by-step printing telegraph are likewise too slow, and are easily thrown out of adjustment by the shock of firing: the telephone is unreliable as the transmitter is packed by the effect of the blast, and is uncertain, since in transmitting figures by speech, especially in the excitement of an engagement, mistakes are frequently made. The system that will successfully solve this problem must be simple in construction, mechanically strong so as not to be affected by the blast, as the receivers are placed close to the guns, rapid in operation, and give a character of record that can be read without liability of error. The communication from the station of the fortress commander to the fire-control commanders is comparatively simple, as, owing to their location and the character of the messages which are exchanged, the telephone has proved satisfactory, but the line of communication from the fire-control commander to the guns is the one in which the difficulties have occurred.

A suitable system is urgently needed, and it is hoped that its development will be achieved by the engineering profession, as upon the successful working of the fire-control communication depends the efficiency of the defense of our sea-coast cities.

A paper presented at the 168th Meeting of the American Institute of Electrical Engineers, at New York, May 28th, 1902.

EMERGENCY ENGINEERING FOR HARBOR DEFENSE.

BY DR. LOUIS BELL.

During the recent difficulty with Spain I had the honor of being the executive and technical officer of the Volunteer Electrical Corps, which was formed in Boston to aid the United States Engineer Corps, and which was charged with the construction of the mining defenses and other emergency work in and about Boston harbor. This corps had, I believe, the distinction of being the first volunteer organization called into the service of the United States on the occasion of the Spanish War, being actually called out for active duty on April 4th, 1898, more than two weeks prior to the actual beginning of hostilities. It had its origin in the resolve of a small knot of electrical engineers headed by Mr. C. D. Haskins, who has dealt with one phase of the subject to-night, to give the best volunteer aid in their power to facilitate the arduous task set before Lieut. John S. Sewell in organizing the defenses of Boston. Lieut. Sewell was in actual command of the work during a large portion of the war, Col. Mansfield, who was officially in command of the station, having been detailed for court-martial duty, which lasted all the earlier portion of the time.

The preliminary organization was formed early in March, 1898, and before the end of the month had grown far beyond the original plan of its projectors. It was an organization in many respects unique. It drew from the strongest electrical organizations in and about Boston and from the ranks of the constructing and consulting engineers who were available for service. The original roster, which was placed on file at the War Department when the plan received official sanction, numbered something over one hundred men, and about one hundred and fifty were engaged in the service at various times. The force consisted of three divisions, one charged with the preparation and loading of mines, another with the laying and maintenance of mines, and the third with the miscellaneous work of establishing communications and performing some of the heavier engineering work which fell to the lot of the corps. Each division was commanded by a division officer, and was again split up into several squads under the direction of squad officers, as responsible foremen. What was practically an adjutant's office was set up, through which the clerical work, purchasing and accounting of the corps was carried on, to be later reported in due form to the office of the U. S. Engineers.

Many of the important electrical organizations in Boston responded most promptly and patriotically to the call for men, telegraph and telephone companies, electrical manufacturers and contractors, joining hands not only in supplying workmen of the most reliable and competent character, but in permitting responsible and able electricians, high in their employ, to drop their regular work and take up their part in the organization of a national defense. It was fortunate that general business was slack during the war, for more than one concern would have found itself seriously crippled had there been anything like the usual pressure.

The corps was never mustered into service; in the first place, for the obvious reason that prior to the declaration of war there was no possible authority under which it could have been mustered in; and second, the body of men was such that they could not have been got together, unless in case of dire emergency, for working under purely military routine. Anticipating a sudden demand for work, an elaborate call system was arranged from headquarters to division and squad officers, and from them to the men, so that the entire body to the last man, I think, could have been gathered ready for orders in two hours from the time that their services were requested.

One fact worth mentioning for future record, in case a similar condition should again arise, is that all members of the organization were pledged to absolute secrecy regarding its operations, and, until it went into service, regarding even its existence; and it is a matter of some pride that its operations were actually kept from the public so long as any secrecy would have been of the slightest service from a military standpoint

The corps was actually called out in part on April 4th and practically the entire work of the establishment of mine defenses, communications and range-finding stations in and about Boston harbor was done directly by it under the direction of Lieut. Sewell, the only extraneous assistance being given by a sergeant and four men, who ultimately were sent up from Willet's Point.

It is not my purpose here to review at length the work which was done. In brief it was as follows:

Two electric lighting plants for the forts were installed, together with search-lights and lighting systems for the casemates; three sections of submarine cable for telephonic and telegraphic communication were laid, connecting the forts with the mainland; a long semi-circle of telephonic communications was arranged, reaching from Nahant on the north to Hull on the south, in part composed of lines segregated from the system of the New England Telephone & Telegraph Co., and in part of aerial lines strung by the communications division of the corps.

Several hundred service mines were loaded, laid and maintained throughout the period of hostilities, following the scheme of defense outlined for the main channels by Lieut. Sewell. An equal number of temporary mines were prepared and made ready for service, for the extension of the mine defenses, by a pair of skirmish lines each nearly three miles in length. Firing stations and range-finding stations were constructed in connection with these skirmish lines and so arranged as to be serviceable for general range-finding purposes. In case of actual hostilities in the district, it would have fallen to the lot of the corps to fight, as well as to lay and maintain mine defenses, and the men were properly instructed in the handling of the mining casemates, which they had equipped.

The subject of the greatest interest at present in connection with this work is the matter of securing and utilizing of emergency material for mine defenses. A sufficient number of standard mines were available to equip in the main the principal channels. Many of the accessories were also put in stock, but the question of obtaining sufficient cable was a grave one. Some standard cable was secured through the U. S. Corps of Engineers, but much had to be bought in any place available and it was hard to find. One of the experts connected with the corps finally unearthed in a neighboring wire factory a couple of machines which could be used at a pinch for armoring, and a considerable amount of cable was constructed to eke out the otherwise scant supply. For telephone cable nothing suitable for submarine use could be obtained from stock or prepared on short notice, and as a last resort a four-wire cable of good quality was lead-covered and laid, with some misgivings as to its durability. It gave excellent service through the period of the war and the first break-down, oddly enough, occurred on the day the protocol was signed. Wire cable for mooring the mines was obtained on the ground, and for supplementary anchors, where such were needed, a lot of old rails answered the purpose excellently. Gutta-percha wire for certain of the mine connections was troublesome to obtain and some special rubber-covered wire, made carefully to size, was tried in experimental fashion, and ultimately we secured a sufficient quantity of the standard wire. The question of explosives was easily solved. A sufficient amount of Kieselguhr dynamite, mostly in long sticks, was obtained for filling most of the standard fuse plugs, but for filling the mines it was necessary to fall back on commercial products and the bulk of them were loaded with No. 1 wood-pulp dynamite, carrying nearly 75% nitro-glycerine and packed rather loosely in 5-lb. paper cartridges. A considerable quantity of blasting gelatine in 5-lb. packages was also used, and on the whole with very good results.

For the emergency mines, after considerable deliberation, we relied on standard beer barrels of the usual size. These were extremely well-made casks, heavily iron-bound and with oak heads 2½ inches thick. For these mines fuse plugs closely resembling the service fuse plugs were made, the firing device being, however, slightly more sensitive. The fuse cans connected to these plugs were filled at the end away from the fuse and sealed with corks and red lead, which appeared to make a joint excellently water-tight, for at least a considerable time. The body of the plug was made to take a large hexagon nut and was cut with a slightly taper thread. The casks were bored by a 3¾-inch ship auger, rigged with long handles and supported by a temporary drill press, and the hole was then cut conical with a special tap made to match the threads on the plugs.

Armored cable could not be obtained in quantities sufficient for supplying the needs of the long skirmish lines of the temporary mines which had been prepared and we therefore fell back upon lead-covered wire. The Spanish fleet was located before the skirmish lines were laid down, so that only experimental mines of this construction were put out, but our results showed that while the lead-covered wire was adequate for all ground cables the risers to the mines would have required constant attention on account of insufficient mechanical endurance of the lead-covering in case the mines swayed and turned for a considerable period in the tideway. For the grouping of the emergency mines, small cast-iron junction boxes were designed and made, which, after the joints were formed in them, were filled with Edison compound, such as is used in the underground service of the Edison Company. This construction appeared to give a tight and durable box, although not one well adapted to stand heavy mechanical strains.

Anticipating some leakage from the long lines of lead-covered cable, a firing plant was erected, consisting of a small 500-volt dynamo connected to a 5 h.p. oil engine, so that even in spite of severe leakage a firing current could still have been passed through the fuses. On account of the great length to be covered, the temporary mines for the skirmish lines were arranged to be fired in groups,separate cables leading back to the firing station from each group. As contact mines, connection was made between the fuse plugs of each group and a firing relay, which served to admit current to the group as a whole. To economize in material, individual mines were designed to carry a charge considerably in excess of the ordinary service charge and were spaced more widely than usual, the interstices being occupied by small kegs carrying contact-firing plugs, only without charge and arranged to admit current to the firing relay for the group.

The skirmish system was laid out in a pair of long, straight lines. Nearly opposite the middle of each line and far inshore was a signal station with a transit instrument in telephonic communication with the firing stations, which were supplied with observation telescopes, the alignment of the line of mines being established by the latter. The particular group over which an enemy might approach could be instantly designated from the bearing obtained from the signal stations, so that the proper group could be fired by observation without difficulty. Incidentally, the firing stations were at sufficient elevation to locate the groups by depression angles, if the communication had been interrupted. Experiments conducted with these temporary mines showed that they had sufficient explosive efficiency and could be spaced at substantially the distance of the standard mines without throwing each other out of action by the explosion.

The principal difficulty encountered in the mining work, was the maintenance of the standard mines in the channels frequented by shipping and where the tide ran rather swiftly. In spite of the most explicit orders and patrol kept up by revenue cutters, vessels sneaked up and down the channels under cover of night and caused almost constant trouble from fouling of cables. At certain points in the channel the mines were kept out of the way by being shackled down low on the anchors as ground mines, but where they were installed in the usual way, keeping them in order was a matter of incessant work and the division charged with this job found itself and a couple of lighters busy nearly all the time.

A considerable number of mines were struck by propellers of passing vessels and sometimes cut open and sunk. I have seen one of the larger service mines, carrying 150 pounds of explosives, cut open by a propeller blade from near the top to down within six inches of the charge. Only Providence, that looks out for fools when it ought not to, prevented at least one steamer from having her stern blown off. Every few days one or several crippled mines had to be taken up, brought back to Fort Independence, which was used as a base for the mining operations, and replaced by another mine. The damaged mines were taken out into the shallows off the channel and exploded, as the easiest way of getting rid of a somewhat dangerous neighbor.

It was found that the wood-pulp dynamite would not stand salt water well, the pulp being apparently unable to hold the nitro-glycerine with anything like the tenacity of the Kieselguhr dynamite. In one instance a striking and nearly calamitous evidence of this was furnished. A large mine had been brought up from the bottom with a damaged fuse plug. It was taken into Fort Independence and one or two men of the corps with a couple of engineer soldiers started to take out the dynamite to examine into the condition of affairs. The whole packages were removed easily enough. Some of those which had come open from exposure to the water were scooped out in the best manner possible, and finally all the dynamite was removed and the interior wiped out with waste. This was before we had had much experience with damaged dynamite, and becoming a bit suspicious of the condition of the mine, which was lying on the parade ground where loading was frequently going on, I directed the soldiers to take it outside the fort and fire a couple of primers into the interior to make sure that it was free from nitro-glycerine. With some covert scoffing they carried out this instruction, and five minutes later I heard a tremendous detonation and as I jumped out through the sally-port I was met with a suffocating volume of smoke. The body of the case, weighing some 400 pounds had been thrown end-over-end a distance of perhaps 50 feet, and with the head complete, was found later in shallow water about 200 yards away from the point of explosion. The nitroglycerine from the damaged dynamite had soaked into all the crevices of the case and formed a coating over its interior in sufficient quantity to produce this unpleasant result when a couple of service primers had been exploded in the interior.

It was usually found that the dynamite which had been wet was not in good explosive condition, and a detonating charge in a small keg was usually placed in or alongside a damaged mine to insure its complete destruction. On one occasion I obtained a fine example of an explosion of the second order in a large mine fired in this way. The detonating charge exploded with great violence, while the mine itself seemed to hang fire for a small fraction of a second, and then came an explosion of a second order throwing up a comparatively small volume of water to a very moderate height. One point with reference to these submarine explosions is worth noting. It was our uniform experience that while after the explosion of a 100 or 150-lb. charge a good many small fish were found floating on the surface killed, nearly all of the larger ones, in fact, perhaps the majority brought to the surface, recovered and swam away; a fact, which may possibly account for the absence of floating fish, alleged to have been noted shortly after the destruction of the *Maine*.

Damaged dynamite which had been removed from mines was sometimes exploded experimentally when merely repacked in the cases from whence it came. Under these circumstances it was sometimes remarkably insensitive, only exploding properly when a cartridge of dry dynamite was used as a primer. The blasting gelatine was subject in a measure to the same defect, and showed a slight tendency to leak nitro-glycerine if a cartridge were left on end, where it was exposed to the warmth of a summer day for some time. This slight instability appeared to be due to the character of the nitro-cellulose used in making it. It did not seem to be uniformly of the nitration required for the production of a first-class gelatine, and commercial gelatine should be employed for military purposes with great caution.

We arranged a little testing laboratory, where we regularly sampled and inspected the explosives delivered and tested them from time to time to assure ourselves that all in the magazine were in good condition. The Kieselguhr dynamite is certainly much superior to the ordinary commercial product in stability and capacity for holding a large percentage of nitro-glycerine. I am convinced that the very grave accident costing the lives of several men, which occurred after the war, while a squad of engineer soldiers was unloading some of the mines which had been taken up, was due to the instability of the explosive producing a hyper-sensitive state, which resulted in detonating the contents of a mine by a very trivial fall.

From our experience with the service mines, which first and last was considerable, I find myself very unfavorably impressed with the contact device then in use and with the method of placing the floating mines. We found constant trouble in the tideway from the twisting off of the mooring cables. The mines in parts of the channels were in a perpetual state of slow revolution, making two or three turns in one direction and then two or three in the other within a period of half a minute or so, and with the result of damaging either the mooring cable or the firing cable in a very large number of cases. Some relief was obtained by allowing more slack, but were I again directing similar operations from a technical standpoint, I should certainly be inclined to employ heavily charged ground mines, used mainly or entirely for observation firing, to a very much larger extent than was the case in 1898. We tested both service plugs and the plugs for the temporary mines, which were decidedly more sensitive than the service plugs, on a number of occasions by running down a dummy mine with one of our tugs, and in most instances the mine was merely pushed aside without making contact. At high speed, or when hitting the mine very squarely, contact would doubtless be made, but were a ship proceeding with the caution necessary in a fog, when observation firing would be impracticable, I think her chance of going through an ordinary line of mines, as then arranged, without firing one by its contact mechanism, would have been very good. In fact, I very much doubt whether, with a mine as near the surface as it is likely to be when a considerable rise and fall of the tide has to be allowed for, it can be provided with a contact device certain to act when struck by a ship and be at the same time sufficiently insensitive to avoid frequent contacts from waves and tidal swinging. I am disposed to think that reduction of the contact feature of the mining system to a set of tentacles, controlling the firing of a deep shackled or ground mine with a very heavy charge, would render it more useful in an emergency and vastly easier to keep in operative condition. I believe such an arrangement is used in the British service. Explosive is cheap and the fewer actual mines the greater is the deadly radius of action of each of them, and the less likely is the fundamental cable system used for observation firing to become disarranged. With contact devices serving merely as tentacles, I think a careful operator in the casemate would soon become acquainted with their idiosyncrasies, so as to fire the mine manually in response to the action of the tentacles with far more certainty than could be secured by contact mines of the ordinary kind. Incidentally, ground mines, with the cables lying on the ooze at the bottom of the channel, are far more difficult to put out of action than mines lying nearer the surface, with a network of mooring cables which can be damaged or cut loose.

Our experience showed what will be of service in future emergencies, that starting with a force of trained electricians and workmen such as can be obtained in almost any large city, the intricacies of a mining system can be very quickly mastered by men having no previous experience with them and mining defenses very quickly and thoroughly organized. This was also the experience at several other points where efficient volunteer organizations were in service.

I presume that had the necessities of the case been more severe, interference with the mining defenses by straggling vessels could have been and would have been very much reduced, but it is a serious matter and one which should be averted, if necessary, by very drastic measures in time of war.

In point of fact, we had but one real alarm at Boston. Once, just after our force had got through its day's work and was scattering, a telegram came from the War Department announcing the appearance of a fleet of uncertain aspect off the coast. There was scurrying for a time and the firing squads were promptly assembled and sent to the casemates. For that night, at least, the mines were thoroughly ready for business, but in the morning our suspense was relieved by the announcement that we had been victims of a false alarm.

After about ninety days' service, the Spanish fleet having been snugly located at the bottom off Santiago, the Volunteer Electrical Corps passed out of existence, but the experience was a valuable one, in showing both the amount of material and men which could be gathered at short notice and in teaching some of the limitations involved in hurried and temporary construction.

Discussion.

President Steinmetz:—We have concluded the presentation of papers, and discussion is in order.

Colonel Reber:—I consider the first paper of the evening one of the most suggestive, and, speaking for one branch of the service, I am sure that the more coöperation we can have from the electrical engineers as a body or individually in solving the problems presented to the Army, the more it will be appreciated by us, not only collectively but individually, and by the War Department as well.

Lieut. George:—I cordially agree with what Col. Reber says. I have noticed in many instances the great advantages that arise by coöperation between the professional electrician in civil life and the naval officer, who is best able to appreciate the conditions existing on shipboard and the requirements of the service as far as the application of electricity to naval purposes is concerned.

With reference to Mr. McFarland's statement as to the desirability of double dynamo rooms on board ship, I would say that many years ago this system of installation was proposed and frequent references are to be found in the early discussions on naval installations. It was contemplated to install a peace dynamo room above the protective deck, in a well-ventilated compartment to supply the normal demands, and a war dynamo room below the protective deck for battle purposes. The improvements in ship's ventilation have rendered this distinction unnecessary. Electric power itself solved the problem by enabling any compartment to be efficiently ventilated. This is particularly the case in the *Kearsarge* and *Kentucky;* the electric ventilating systems of these vessels are most admirable, due to the efficiency of the electric drive and the arrangement of piping. There are several foreign men-of-war equipped with double dynamo rooms. A recent Italian ship has an arrangement very similar to the scheme proposed for the 16,000-ton battleships, except that no dynamo room is sufficiently empowered to supply the entire battle output. Each dynamo room is capable, however, of operating the load of lamps, and all auxiliaries at reduced speed.

I have recently seen an opinion expressed by an eminent officer of the French Navy, on this subject. He does not advocate dynamo rooms widely separated, but suggests that the rooms be entirely independent electrically, that each be capable of handling the battle load, but that they be situated close together, in a central position for economical distribution, and separated by a water-tight bulkhead, communication being made by signalling appliances.

The Navy specifications set the following as the allowable temperature rise after a 4-hour run at full rated load. Armature and field 33⅓°C., commutator 40°C., shunt rheostat 75° C., and series shunt 40°C. In the report of the Committee on standardization, it is recommended that the following maximum values of temperature elevation should not be exceeded. Armature and field 50° C., commutator and collector rings and brushes, 55° C.

The high temperatures in the shore installations referred to by Mr. McFarland are the exception and not the rule, and the commercial practice as indicated by the report of the Standardization Committee contemplates the normal condition of installation rather than the few isolated cases that occur in which dynamos are installed in hot and poorly ventilated cellars.

It is not uncommon on board ship to find temperatures of a dynamo room recorded in the electrical log books at from 120° to 130° F., for periods of several hours duration, and in some cases the temperatures are in excess of these figures. If we take 125° F. as a temperature to which naval generators may be subjected for several hours and the maximum permissible temperature rise accords with the specifications, the armature and fields will reach 185° F. This, under the commercial practice, would be the temperature of the armature and fields of a machine running in a dynamo room at 95° F., which would represent a common average during the summer. I think it is safe to say that the temperatures of our dynamo rooms average 30° or 40° F., higher than those on shore.

Mr. McFarland cites the inexperience and lack of skill of the men entrusted with the care of electrical apparatus on board ship. The early installations were looked out for by the gunner's gang, good men in their way, but without experience in electrical work. The electrical force nów consists of men specially selected for this purpose, rated as chief electrician and electricians of the first, second and third classes, with a scale of pay more commensurate with their duties, and the growing importance of electricity on shipboard. I have frequently heard references to lack of care displayed in the operation and maintenance of ships' plants and I am of the opinion that it is more assumed than real. The best answer to the question is that the electrical portion of our personnel does operate and maintain expensive and elaborate light and power installations for years at a time, far removed from sources of supply and facilities for repair, and under conditions much more exacting than those obtaining on shore.

As regards the direct current motor, it performs its duty whenever installed, and I can see no reason why it could not be installed whenever the electric drive appears desirable. On the *Kearsarge*, the boat cranes were operated by direct current motors, mounted on turntables on the rails, exposed to the weather, and frequently flooded by seas breaking over the rail. During my term of service in this ship, some eighteen months, these motors were in constant use day and night and I do not remember a single instance of breakdown. The same remark applies to the electric deck winches, which were always ready for action. So successful have these motors been, that the steam drive originally prepared on the ships under construction for manipulating boat cranes, have recently been changed to electric power. I consider the direct current motor eminently adapted to the forced draft system, the inaccessibility of the location being in my mind a prime factor for preferring it to the reciprocating engine.

GENERAL EUGENE GRIFFIN:—I have listened with very great interest to the reading of the papers of the evening. I think they been very instructive to us all.

The method followed in our country has been to have a comparatively small standing army, and to rely upon volunteer troops in time of war. Thank God, we have a larger army now than we had ten years ago, but it is still small in comparison with the necessities in time of war, and we must always call upon the volunteer troops to build up our army. We must in the same way, of course, call upon our volunteer scientists in times of war, however well equipped we may be with those who have studied at the national academies. It goes without saying that when the emergency arises there will not be enough trained men. We must have a force which is able to execute the work under the direction of the proper officers. and that force must be taken from the men who up to that time have been doing their work in civil life. Mr. Haskins' work has been spoken of, and I happen to know something of his experience in Boston, and I wish to endorse cordially what has been said by Col. Reber and Capt. Sewell as to the services that Mr. Haskins rendered there.

When the emergency comes we must also call upon the manufacturers. I happen to have been in the Corps of Engineers, and I know something of the conditions of the Corps In talking with some of the engineer officers in Washington about the time of the breaking out of the Spanish-American War, I asked them what they were going to do about searchlights at the fortifications I remarked that when I resigned we had only one searchlight for the entire fortifications of the United States. They said as soon as they had some money they were going to buy some. Forseeing what the conditions were, and realizing the necessity of getting large lenses, I cabled to some of our people abroad and directed them to buy every 24, 26 and 36-inch lens in the market. Within one month they bought eight lenses, and a week afterwards seven more, and they could buy no more. That is simply an indication of the difficulty of getting very quickly that kind of material which is necessary in times of war. I want to add simply that I hope the result of this meeting will be to bring about some cöoperation between the officers of the Army and Navy, and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, which will lead to the possible organization of some kind of volunteer electrical corps, and which will lead to that closeness of relations which I am sure will be of very great value to the country in case of any further hostilities with foreign nations

MR. ARTHUR V. ABBOTT:—There is one paper this evening that puts me somewhat in the position of Oliver Twist; that is, I wish there was more of it. I refer to Lieut. Beecher's paper upon the transmission of intelligence without wires. It is a subject in which I was very much interested some time ago when I had more time to bestow upon that portion of the electrical field which is experimental; so the chief thing I have to offer in the way of discussion this evening is some questions. Could Lieut. Beecher tell us anything as to the amount of power required to transmit signals over varying distances? Can we have any information as to the speed which signaling has attained? How many words a minute can be sent? How fast can transmission be, particularly with the newer forms of receiver? What is the best form of telephone for receiver; the high-wound or the low-wound receiver? Mention is made of increasing the height of the masts on vessels; is that done because greater distances can be attained by increasing the heights of the masts, and has any new formula been developed since the one enunciated by Marconi, that the distance varies as the square root of the height of the mast? The use of the anti-coherer is certainly novel. In that type of receiver is a telephone employed, and are the audible signals produced by a variation of current in it? Have any experiments been carried on as to the actual transmission of speech? I made some experiments in that line myself, and I succeeded in transmitting speech over short distances, but it was not successful when attempts were made over a mile or two. Possibly that was owing to the conditions which the paper mentions,—the difficulty of transmitting signals of any kind on land. We all know that very few successful experiments over long distances have been made in the transmission of signals of any kind over land. What kind of a microphone is the best? Is the carbon microphone the best? Why should not a telephone receiver be a good receiver? If my five minutes is not up, Mr. President, I would like to have the remainder of it used by some of the gentlemen in answering the questions that I have asked.

LIEUT. BEECHER:—I do not think I can answer all the questions that the gentleman has asked. Moreover, I have not jotted them down, and I will ask him to recall the questions to me and I will endeavor to answer them as far as I can.

MR. ABBOTT:—First, the amount of power?

LIEUT. BEECHER:—I cannot say off-hand the amount of power used, but I can say that very little power is required. I do not know how much Marconi used, in his recent long distance (Trans-Atlantic) experiments, but I do know that he was using very much more power than has been used heretofore.

MR. ABBOTT:—What about the length of sparking distance?

LIEUT. BEECHER:—With a coherer receiver, signaling 40 miles over water, about 1½-inch sparking gap is ordinarily employed, using Prof. Fessenden's receiver. I noticed some experiments where he was signaling about the same distance (45 miles) over fresh water, which is harder to signal over than salt water, and where he was only using between ¼ and ½-inch spark gap.

MR. ABBOTT:—What about speed?

LIEUT. BEECHER:—The best speed, using a coherer receiver, is, I suppose, about twelve words a minute; but with a telephone receiver that can be increased very largely. With Prof. Fessenden's apparatus a few weeks ago, down in the North Carolina swamps, he was signaling with unpracticed operators about 25 words a minute. The speed with his apparatus was only limited by the ability of the operator to send and receive. You might say it was more rapid than any land instrument could be worked.

MR. ABBOTT:—What about the height of the masts?

LIEUT. BEECHER:—I think most people have changed their ideas about the height of the masts affecting the distance of transmission as the square root of the height. I think the distance varies more nearly as the height of the masts.

MR. ABBOTT:—I think Signor Marconi was the originator of the law that it varied with the square root of the height.

LIEUT. BEECHER:—I do not think I have seen that statement of his.

MR. ABBOTT:—I think you will find it in a paper of his published or read before the INSTITUITON OF ELECTRICAL ENGINEERS of England about two years ago.

LIEUT. BEECHER:—I cannot state definitely about that. From my own knowledge and experience, I do not know; but I have an idea that the distance of transmission varies more nearly as the height. I think perhaps Captain Russell or Col. Reber can answer that question better than I can.

MR. ABBOTT:—I also think Col. Reber could give us some information on this subject.

COL. REBER:—I can say that so far as my own experiments are concerned, I have not worked with sufficiently great distances to prove whether or not "the law of the square root" is correct. I have assumed in a general way that Marconi's statement is correct when the energy is the same at the different distances, and until I have more data I would not like either to affirm or deny the statement. We worked over certain distances and got certain results, but the great difficulty with the ordinary coherer is that its sensitiveness, not being the same on two different occasions, the height for the distance on one day would not be the same for the same distance on a subsequent day.

MR. ABBOTT:—That is exactly the same experience that I have had.

COL. REBER:—I think that with Fessenden's coherer he can work a much greater distance with less energy, because this type of receiving apparatus works on an entirely different principle from the coherer. He has shown his system to several officers both of the Army and Navy, but as yet has not published his methods, owing to the patent situation.

MR. ABBOTT:—Can you tell us something more about the anticoherer?

LIEUT. BEECHER:—I just brought that out because it seems to me to be so radically different from the coherer. Take a mirror and scratch it so as to divide the silvering and connect the portions up in an ordinary cell circuit; the effect of the spark there is just the opposite from the effect with a loose contact, or with a coherer. In other words, the action of the spark materially increases the resistance of the circuit, instead of reducing the resistance, as it does with a loose contact.

MR. ABBOTT:—Do you think that offers any new form of transmitter?

LIEUT. BEECHER:—It has been utilized abroad, and it is utilized in the De Forest system in this country, which I do not think has been made public yet, but I understand he has gotten some very good results in speed, and claims quite good results on distances. It has also been used abroad in some of the German systems.

MR. ABBOTT:—I think Prof. Bose was the first one to call attention to the varying, so to speak, coherer action. Have you made any experiments in the transmission of speech?

LIEUT. BEECHER:—No, sir, I have not, but Prof. Fessenden claims, and I have no doubt his claims are very well substantiated, that with his system he has completely solved the question of the transmission of audible speech, and, as Col. Reber says, his system has not been given out to the public yet on account of the foreign patents. Without doubt his system is better adapted to that than any other I have knowledge of, and he claims that he can transmit audible speech.

MR. ABBOTT:—Are there any facts as to the kind of microphone?

LIEUT. BEECHER:—No, sir, I have not any. Of course, a great many different kinds have been experimented with. I witnessed a very interesting experiment conducted by Capt. Russell the other day. If he will tell us something about it I think it would be very interesting to you all. It brought very forcibly to my mind the using of a loose contact with a relay and Morse recorder. I did not know when I saw Capt. Russell's apparatus that this had been done before, but afterward in reading on the subject, I found that Prof. Branly had done the same thing. Of course the coherer, as we all know, is very unreliable. The more we reduce the number of filings, perhaps, the more reliable it is.

MR. ABBOTT:—In other words, the more you work it, the worse it is.

COL. REBER:—I will answer one of the questions about speed. In one of our installations, where seven or eight thousand words are sent daily, the average rate is about twelve words a minute, but would sometimes run to twenty-five or twenty-six words, using the ordinary coherer.

LIEUT. GEORGE:—I would like to ask for reliable data as to the steam turbine. It would appear from the advertisements and tables of performance published by the manufacturers from time to time, that the water consumption of a steam turbine, coupled to a generator, per kilowatt hour, is much less than that of a reciprocating engine of the same capacity. Also that the variation in consumption is not so great as the difference in water consumption between large and small reciprocating engines, and in all cases the steam turbine appears more economical than the reciprocating engine. If any member of the INSTITUTE is in a position to give me the figures from actual tests and any information as to the performance of the various types of bearings in this connection, I would be much obliged to receive it at Washington. This would be in line with the coöperation referred to this evening

PRESIDENT STEINMETZ:—We have with us here to-night Gen. Greeley of the United States Signal Service, and I should be very pleased to have him address us.

GEN. A. W. GREELEY:—The Secretary was kind enough to ask me to write a paper for this occasion, but I was not able to do so; I have not been able to formulate any remarks for this evening, either. I have listened with great pleasure to the papers, and with profit. I would like to say that the spirit of coöperation between the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the Army and Navy branches of the military service of the United States is fully in accord with my own ideas and practice. I am very sorry for any chief of bureau who has of necessity to call in outside help for the men of his corps, but, on the other hand,I am very sorry for a chief of a bureau who does any very important work through the officers of his corps when he can get it done by the civilians of his country. It has been my belief that a man who does a thing well from early Monday morning until late Saturday night can do it better than any officer of the Army or Navy. I have, in the Signal Corps, officers who are capable of doing any class of electrical work, but I have never permitted them to do any piece of work which I could hire done by a civilian. The work on the south coast of Cuba, and in the interior of China, and in the Philippines, which has brought a certain credit to the Signal Corps of the Army, and I believe a still greater credit to the American nation, has been forced by war conditions upon the American soldier, and I believe the American soldier is, as the American himself, the best type of his kind. Many are fond of speaking of the difference between the regular army and the volunteer army. Gentlemen, there is no difference. They are all volunteers. The only thing is that the regular comes in for three years, while the volunteer comes in for three months, or nine months, or a year, as the case may be. They are men of the same education, of the same standing, and, whenever Congress in its wisdom puts limitations on them, applies what I have said is the proper doctrine for the Army, as it is for the evolution of American industry, the doctrine of selection, of competition, and of elimination—when these things are given to a corps, as they were given to the Signal Corps at the beginning of the Spanish-American war, there always will be results satisfactory to our people. Because Congress did permit the Signal Corps of the United States, or the chief signal officer of the army, to enlist or commission in his corps, men of whom two-thirds must be electricians or telegraph operators, that moment it was a certainty that the work done by the corps would be successful. I have always followed those lines, and I believe that if the country in the future will follow those lines, that when we call out our volunteer army it will be a worthy supplement to the volunteers whom we call regulars.

I am very much gratified that the spirit of the Army and Navy has turned to the assimilation of the engineering talent of the country. Von Moltke has well said that war is the only science that lays under tribute all other sciences; and, in this country, where we have such striking illustrations of the resourcefulness and ingenuity of the Americans, we believe the American soldier, who is first of all an American citizen, can and will, in the twentieth century, place himself on as high a level, as he has in the nineteenth century. To this end, of all things the most important in my mind is the question of electrical power and communication, in connection with military movements. The bringing together of the great forces of nature to be utilized for the building up of the country is a great thing, but to us in the Army and Navy, we feel that it is much more to our mind to be able to bring these same forces together to save the nation. I am sure we have with us to-day many men who have done work, as I am told Mr. Haskins did, which gave the country a feeling of satisfaction when the phantom fleet of Cervera was seen hovering off so many shores.

I am thankful, gentlemen, for your courtesy, and I feel that the Army and Navy owe a vote of thanks to your society for bringing forward this question, which is an important one—the use of electricity by the Army and Navy of the United States.

MR. CALVIN W. RICE:—(Chairman of the Committee on Papers and Meetings) Speaking for the Committee, I want to say we owe our gratitude to the officers of the Army and Navy who have come here to-night and given such an interesting meeting. The members who have been moving about the hall have heard a great many speak of what a profitable meeting this has been, and in the name of the INSTITUTE, I thank the gentlemen of the Army and Navy for their interest and coming here to-night.

MR. GEO. T. HANCHETT:—Referring to wireless telegraphy, I am going to venture a few remarks, in the hope that though they may be of lesser value, they will elicit from the experts we are fortunate to have with us, some valuable suggestions. I have not followed the literature of wireless telegraphy as thoroughly as I should, and I have nowhere read of any investigations or discussion as to why a coherer coheres. It has been generally accepted as a fact that it does cohere, and in the absence of investigations of this character, it seems to me that we have been searching somewhat blindly for a coherer that works. I am going to speak of some investigations that I conducted. I will illustrate on the blackboard. I took a slip of glass and cemented to it by means of shellac, two fine wires, so that the gap between them could be focused under the objective of a microscope. I placed between these points light powders of different kinds and observed the action when one side was connected to a mast of wire and the other to the earth, the entire system being influenced by the sparks of a distant induction coil. The results were substantially these: The wires appeared, of course, very large and the dust particles appeared as heavy lumps. Upon the spark of the induction coil passing, there was at once a mechanical motion of the particles, which cohered. With the metals in some of my coherers with which I could not send a dash, I found that the particles cohered and then flew apart. I then substituted light powders, which were not necessarily conductors, scrapings of chalk, lycopodium and the like. I found that powders flew together, cohering and instantly decohering. The conclusion seems to be that the action is electrostatic attraction and repulsion. If these things are true, it affords some interesting speculation as to what is the proper thing to use for coherer work. In the first place the powder must be light to respond readily to the minute forces acting upon it. In the second place it must be conducting. Any powder that appears to have the least tendency to be an insulator, due to oxide on its surface, is self-decohering to a very annoying degree. Silver-plated aluminium particles suggest themselves as perhaps being valuable for such work. My own experience has been that the filings from an ordinary American three-cent piece, gave me much better results than the filings from many expensive metals, and I may say that I tried all that could be obtained without great difficulty. If any one has anything further on this subject, I should be very much pleased to get the information.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NINETEENTH ANNUAL CONVENTION.

GREAT BARRINGTON, MASS., June 17-21.

In order that the professional work of the Convention might begin promptly on June 18th, the Committee on Papers and Committee on Transportation, arranged for a special train leaving New York at 2 o'clock June 17th, and reaching Great Barrington at 5.30 P. M. Seventy-three members and guests availed themselves of this arrangement, in order that they might attend a reception in their honor, which the Local Committee in conjunction with the Thursday Morning Club had planned for that evening.

At nine o'clock the members and guests assembled in the Music Room of the Berkshire Inn, were cordially greeted by the ladies and gentlemen of the local Reception Committee. An address of welcome by Mr. William Stanley, Chairman of the Local Committee, was given as follows:

" MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:—A very pleasant though unfamiliar duty has fallen to my lot this evening, for I am instructed by the good people of Great Barrington, by their neighbors in the adjacent villages, by the Mayor and the citizens of Pittsfield, in fact, by all the inhabitants of the hills and valleys of Berkshire, to extend to you a most hearty welcome. A year ago, when we sent you an invitation to hold your meeting among us, we were well aware that we could not hope to offer to you the attractions that are most intimately associated with your profession, attractions which you have been accustomed to find when assembled in the larger cities of the country, for we have few engineering enterprises, and the arts and sciences are not widely practised among us. I may as well confess it—we are a simple pastoral people dwelling among these hills. To us no pastures or meadows are so green, no mountain brooks so joyous, no pines so fragrant, no elms so stately as those of Berkshire. Upon this very spot, some seventy years ago, there dwelt one of the sweetest singers of the era, who, in "Thanatopsis," " The Water Fowl," " Green River," and other poems, expressed the inspiration he gathered among these hills. A little way up the valley Hawthorne lived beside a lake and wrote those wonderful stories that have made his name immortal. From Stockbridge, near at hand, came Field, the man who dared to lay the first cable beneath an ocean. Just down the street, in an ancient house, Franklin Leonard Pope, second President of this INSTITUTE, passed his boyhood days and met his most untimely death; and so I might almost indefinitely extend the list of those who, carrying from these hills and valleys most noble thoughts have done much for their country. While we rely to some extent upon the natural beauties of our country to make your visit pleasant and agreeable, we would hardly have dared to undertake the responsibility of entertaining you on this occasion had nature been our only attraction. We shall hope to persuade you that not even June arrayed in her loveliest robes is as fair as are the ladies who are to assist us during your visit. Our little village can point with pride to the Thursday Morning Club. We have entrusted to them the conduct of such functions as we shall be able to offer to you, a decision which I am sure you will heartily endorse. I know that I am expressing the sentiment of your hosts this evening if I have made plain to you in this brief message that our most cordial greeting is not only extended to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, but that it also has a personal significance to each and every one of its members."

By special request of President Steinmetz, the response in behalf of the INSTITUTE was made by Past-President Martin, who eloquently thanked the Committee for the hearty welcome extended to its members and in line with Mr. Stanley's remarks paid a feeling tribute to the memory of the late Past President, Franklin Leonard Pope.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington. Mass., June 18th, 1902.

A METHOD OF COMPOUNDING ALTERNATING CURRENT GENERATORS AND MOTORS, DIRECT CURRENT GENERATORS, SYNCHRONOUS MOTOR-GENERATORS AND SYNCHRONOUS CONVERTERS.

BY FRANK GEORGE BAUM.

The weakest element in the regulation of an alternating current system is usually the generator. Makers of engine and water wheel governors are able to keep the variations in speed in the machines which they send out much lower than builders of A. C. generators are able to keep the variations in voltage. The time is past when the man who is selling a generator points with pride to the fact that the machine may be short-circuited with little increase over nominal current. The argument that compounding of alternating current generators is not necessary because load changes are not rapid, does not hold, as the fluctuation of voltage of 10% or more in some stations testifies. Working an alternating current station without compounding is equivalent to operating a direct current station with shunt-wound separately excited generators. When induction motors are to be operated, as is usually the case, the conditions are worse. No electrical engineer would install shunt-wound direct current generators, even if the load changes were not rapid, and the only reason for not installing compounded alternators is that there is at present no method by which the compounding may be produced for large stations. There are methods of compounding single machines which are more or less successful, but no method, I believe, for large stations, which gives results that can be compared with those obtained by compounding D. C. generators.

The following method of compounding alternating current generators for any load and any power factor, so that we may get results equal to those obtained by compounding D. C. generators will, I believe, commend itself to electrical engineers. In some respects, the method is simpler than in the case of D. C. generators, as will be shown.

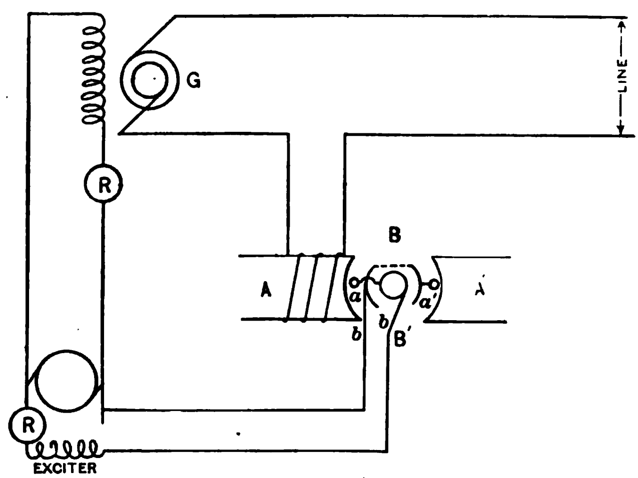

FIG. 1.—Showing Possible Connections of Compensator.

Fig. 1 shows the connections of the " compensator," as it may be called. G is the generator, which, for the purpose of explana-

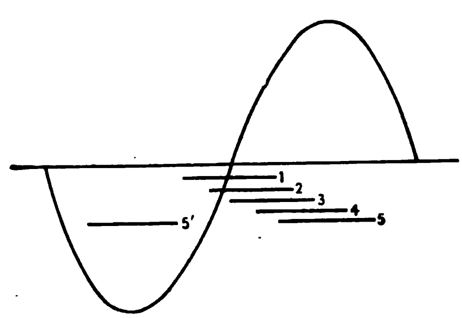

FIG. 2.—Showing Method of Obtaining a Rectified Potential.

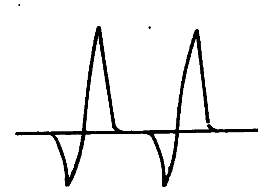

FIG. 3.—Trace of Oscillograph Record for Second Position in Fig. 2.

tion, may be considered a two-pole machine. From its shaft is driven the armature of the compensator $a\ a'$, having field poles A A'. The armature winding may be considered a single turn of wire, as shown. One end of the armature wire goes to a solid ring, and the other end to a ring broken as shown, but the two parts are metallically connected. It is to be noticed particularly that there is no commutation, the same armature wire being always connected to the same brush. Brushes are placed on these rings as shown, the brush on the broken ring being in the center of one pole. The metallic segments of the broken ring cover about 90 electrical degrees.

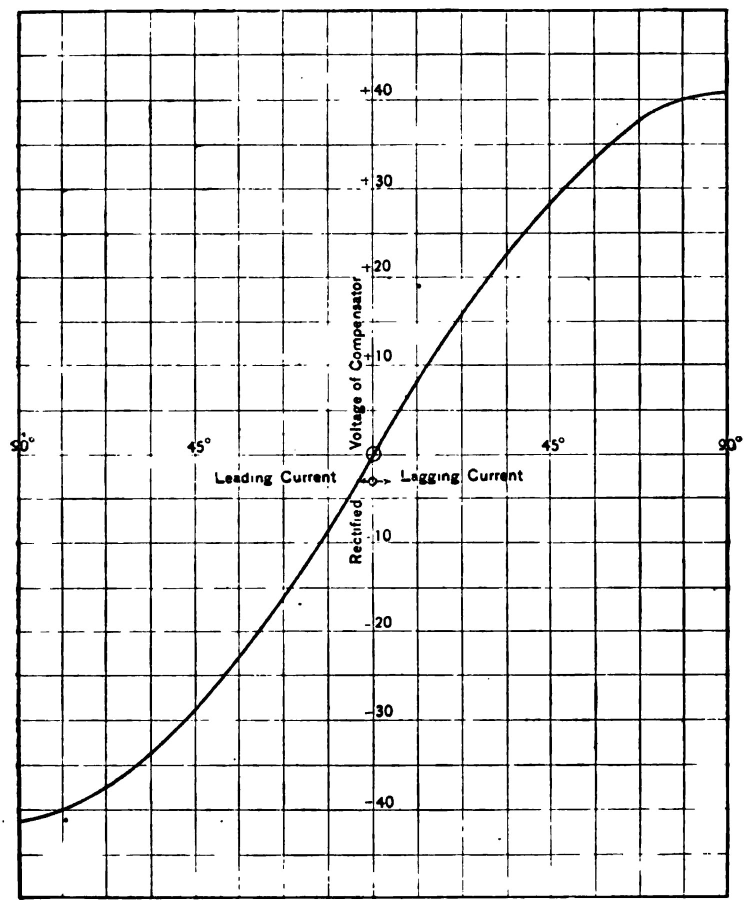

Fig. 4.—Curve of Rectified Voltage of Compensator, with Constant Field Current and Variable Angle.

If the field A A′ were excited by a direct current we would get at the brushes, parts of an alternating wave, a part of each wave being cut out owing to the fact that the ring is divided. If we excite A A′ by a sinusoidal alternating current in synchronism with the rotation of the armature $a\ a'$, we get waves of e.m.f. at the brushes of different forms, depending on the position of the armature coil when the current passes through its maximum value. For example, if the armature coil passes the position shown when the current in the field coil is a maximum, it will be evident that we get a rectified potential at the brushes *b b*. We really cut off the top of the wave and thus get a potential at *b b* which may be measured by an ordinary D. C. voltmeter. If the current in the field passes through zero when the armature coil

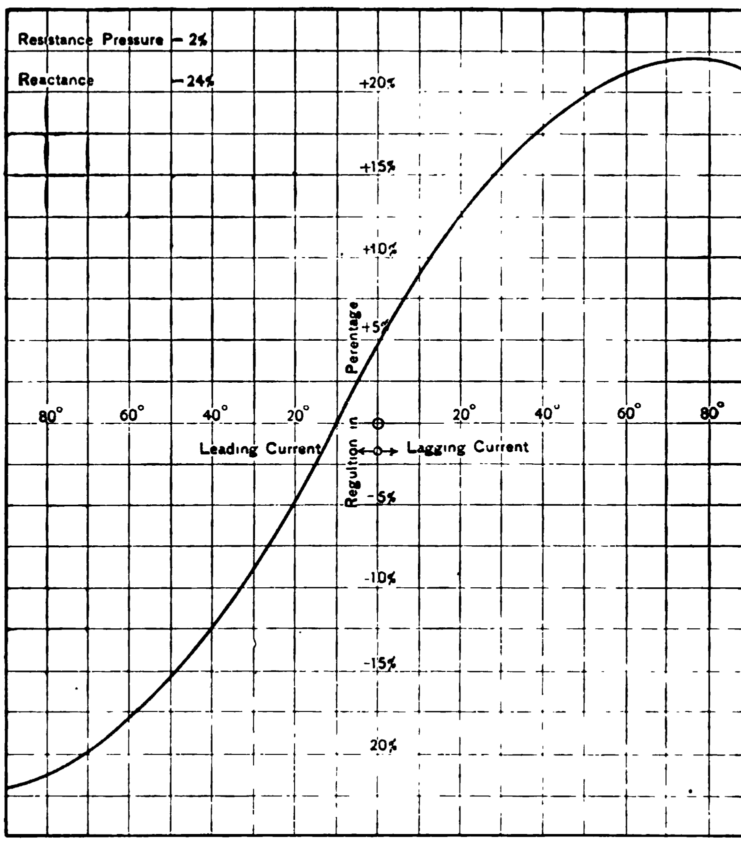

FIG. 5.—Regulation of Generator on Constant Armature Current and Variable Power Factor.

passes the position shown, then we get no rectified potential.

What really occurs for the different positions may be explained with reference to Fig. 2. The sine wave is the wave of current from the alternator, and may also represent the wave of magnetism in the compensator poles A A′. The lines 1, 2, etc., represent the metallic segment for different positions of the armature coil with respect to the wave of magnetism. If the current is passing through zero when the coil is in the position shown in Fig. 1, then we cut off the part of the wave under the line 1, and hence get an alternating potential. There will also be an alternating e.m.f. due to the transformer action, but no account need be taken of this. Now, suppose the current lags behind this position. This is equivalent to a motion ahead of the metallic segment with respect to the wave of current. For the position 2 of the metallic segment, we would cut off that part of the wave under the line 2. Fig. 3 shows a trace of the e.m.f. wave for the second position in Fig. 2. This record was taken with a Blondel band oscillograph. As the current lags more and more, we pass through the positions 1, 2, 3, 4, to 5, for a lag of 90°, which gives us maximum rectified potential. If the current leads, there is a relative motion between the wave of magnetism and the metallic segment in the opposite direction. For 90° lead we get the position 5′, giving us a reading equal and opposite to that obtained for the position 5.

Fig. 4 shows a curve between the voltage read by a D. C voltmeter across *b b* and the angle of lag of current (the zero angle does not correspond to a non-inductive current from the generator, but corresponds to the position 1 of the metallic segment in Fig. 2), the current in the field of the compensator being constant. The form of the rectified voltage curve may be changed very easily by varying the arc of the metallic segment. It will be seen that the curve in Fig. 4 is very similar to that shown in Fig. 5, which shows the regulation of a generator delivering constant current, but at different power factors. (By the regulation is meant the percentage by which the generated pressure must exceed the terminal pressure.) We get this same kind of a curve for the regulation of a transmission line. If it were possible, now, to add to the excitation of the generator, amounts proportional to the ordinates in Fig. 5, we would obtain a generator which would regulate on any load and any power factor from 90° lead to 90° lag. The field poles A A′ may be rotated with respect to the armature so that when the alternator is working on a constant load, the different voltages across *b b*, shown by the curve in Fig. 4, may be obtained. Now, we set the poles A A′ with respect to the poles of the alternator, when the alternator is working on a non-inductive load, to correspond about to position 2 for the metallic segment in Fig. 2. That is, we work approximately, as many degrees to the right of the zero point in Fig. 4 as the current lags through the generator. This point may be easily found with a D. C. voltmeter across *b b*, as we merely rotate the field until a certain fraction of the maximum voltage is obtained. This setting takes but a moment and may be made

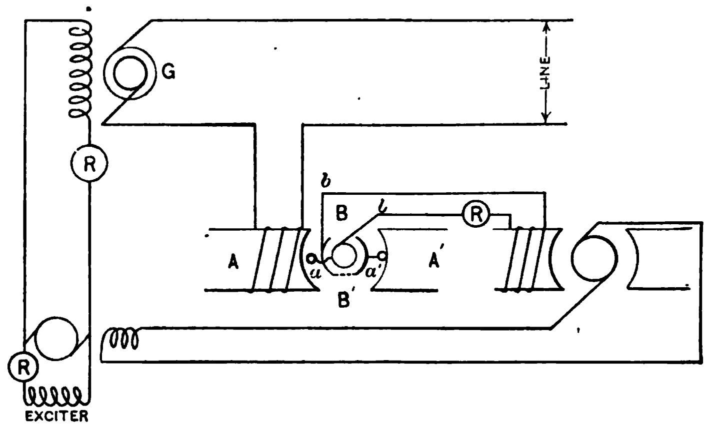

FIG. 6.—Showing Connections of Compensator Used in Practice.

while the alternator and compensator are running

The rectified voltage may now be added to the alternator in several ways. If, then, the current delivered lags behind the

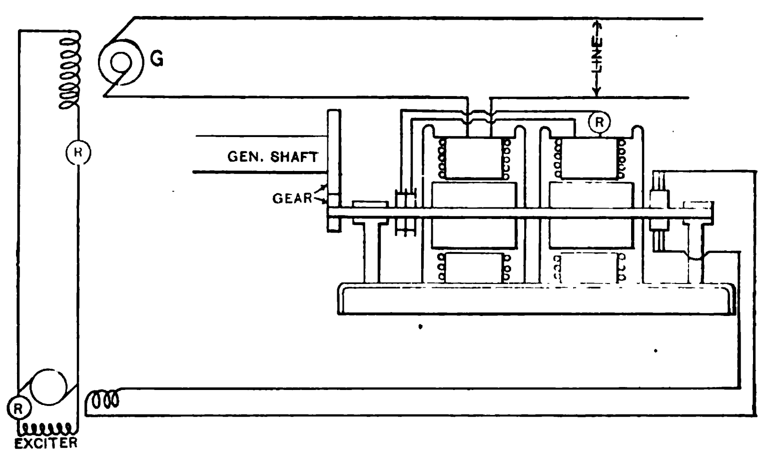

FIG. 7—Compounding Generator or Synchronous Motor, Showing General Arrangement of Compensator.

terminal pressure of the generator, the potential added ill increase according to the curve in Fig. 4. If the current leads, the voltage added will decrease, pass through zero, and then increase in the negative direction.

The rectified potential may be added in series with the exciter field, as shown in Fig. 1. This method gives very good results. It is found that loads of any character may be added to the machine without disturbing the voltage. The generator may also be over-compounded to maintain constant potential at some point on the line.

There are some objections, however, to this arrangement, because it is not "fool proof." The arrangement shown diagrammatically in Fig. 6 has therefore been adopted. As shown, the rectified potential is used to excite a small D. C. generator of 100 to 500 watts capacity, and the armature of the D. C. machine connected in series with the series winding on the exciter. The D. C. current is large, so that only a few turns are needed on the exciter. These may be easily threaded on by hand, if there is not already a series winding on the exciter, so that no new exciter is needed. The percentage compounding may be changed simply by turning the rheostat handle in the armature circuit of the compensator. The compensator has four poles and is driven in synchronism by a gearing on the generator shaft. Fig. 7 shows the general arrangement of the compensator. The compensator set being small, it is a simple matter to add the compensator to any generator.

This method may be applied to compounding alternators operating in parallel, whether the generators have separate exciters or are all excited from the same exciter. When there is a separate exciter for each machine, the compensator may be applied to each generator, or a single compensator may be put on one generator and the current from the D. C. side carried around each exciter field. The station will then, of course, be compounded only when the compensator is running. The entire station may be compounded by a single compensator set where all generators are excited from the same exciter. In this case, the current for the field of the compensator would be taken from the bus-bars.

Since we must supply only a fraction of the exciting energy of the exciter, the compensator set of 500 watts capacity is large enough to compound a 10,000 k.w. station.

Another method of obtaining a rectified potential is that used by Mr. Fitzhugh Townsend[1] in determining the curve of an al-

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1—"A New Method of Tracing Alternating Current Curves" by Fitzhugh Towsend, *Transactions*, January, 1900.

ternator. His contact maker consisted of a disk, the perimeter of which in a bipolar alternator, is divided into two sections. One section only is conducting and current flows only for half a period.

This method differs only in detail from that used in commutating the current in the compensator types of alternators now on the market. For numerous reasons this method of compounding is not entirely successful and cannot be used to compound machines running in parallel. The alternating current cannot be successfully rectified, applied directly to the field of the alternator to produce the compounding. If however, we apply the rectified voltage to the field of an auxiliary exciter, the troubles due to commutating the current disappear.

It will be seen that this method of compounding is in some respects simpler than the present method of compounding D. C. machines. The following are some of its advantages:

(1) Generators have a single winding.

(2) No equalizer bus-bars, switches, etc. are necessary.

(3) No adjustment of low resistance shunts is necessary to make machines take their proper share of load.

(4) When the generators are over-compounded, there is no drop in voltage when a fresh machine is added.

(5) Percentage compounding may be changed instantly by turning a rheostat handle.

(6) The cost of compounding a large station will be less than compounding the same number and capacity of D. C. generators.

(7) Owing to the absence of equalizer switches, the operation of the station is simpler.

Compounding Synchronous Motors.

At the present time, there is no method of compounding the excitation of synchronous motors other than those driving D. C. generators. The method given for compounding alternating current generators may be used to compound the excitation of alternating current motors. This removes one serious objection to the use of synchronous motors on transmission lines for other purposes than for operating D. C. machines.

Compounding Direct Current Generators.

The method given for compounding alternating current generators is comparable with the method of compounding D. C. generators shown in Fig. 8. Here we excite all the D. C. generators by one exciter and compound this exciter with the load current from the generators. This does away with the series winding on each machine, as well as all equalizer connections and switches. We are not bothered with the troublesome problem of adjusting a number of low resistance shunts in such a way that all machines will take their proper share of load. There will be no reversal of magnetism and less " slopping over " due to the reversal of the series current. Except for the addition of the exciter, the operation of the station is very much simplified. To provide against the possibility of an injury to the exciter and the consequent disabling of the entire station, the generator fields should be provided with double-throw switches, so that in case of injury to the exciter the generators could be temporarily operated as shunt-wound machines. Shunts 1, 2, 3, etc., with switches, may be put on the exciter

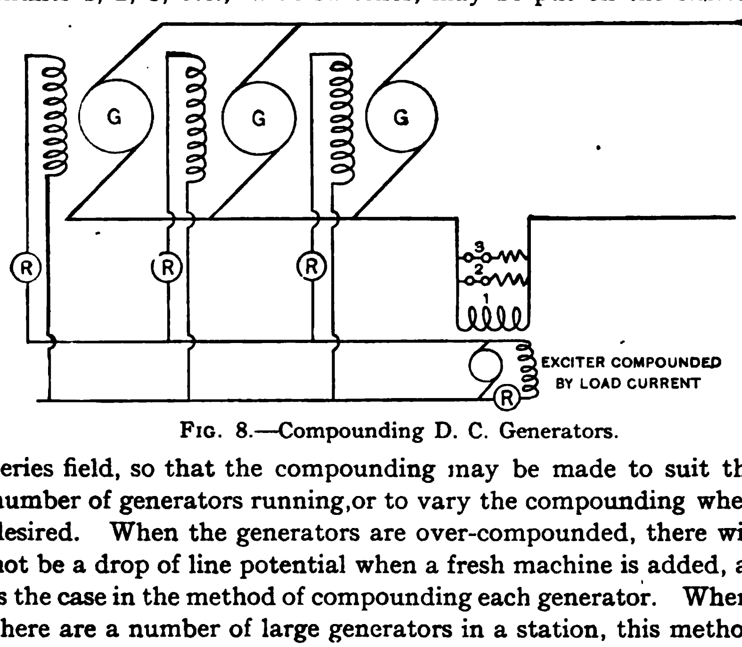


FIG. 8.—Compounding D. C. Generators.

series field, so that the compounding may be made to suit the number of generators running,or to vary the compounding when desired. When the generators are over-compounded, there will not be a drop of line potential when a fresh machine is added, as is the case in the method of compounding each generator. Where there are a number of large generators in a station, this method of compounding seems to be cheaper and simpler in nearly every way, than that commonly used.

COMPOUNDING SYNCHRONOUS MOTOR-GENERATORS AND SYNCHRONOUS CONVERTERS.

The above method of compounding the exciter has been very successfully used to compound the excitation of three motor-generator sets operating on a street railway load at the end of a 150-mile transmission line. The arrangement is shown in Fig. 9

for a single set. All the synchronous motors were, of course, excited from the same exciter. No new exciter was needed, as the motors were already excited by a compound wound exciter. All that was necessary to apply the method was to shunt part of the current from the D. C. side around the exciter series coil. This varied the excitation of the motor so that changes of load had little effect on the line potential at the motor terminals. Before the synchronous motors were compounded, lights could not be operated on account of the excessive variations of potential.

Since a separate exciter is generally used for this kind of work, this method is very much cheaper and simpler than carrying a series winding around the field poles of each motor. This method may also be applied to compounding synchronous converters.

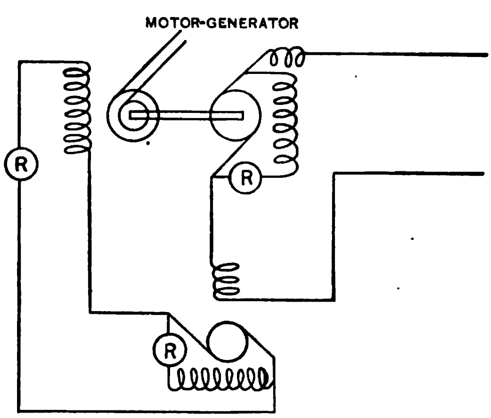


FIG. 9.—Compounding Motor-Generator.—Exciter Compounded by Load Current.

COMPOUNDING TRANSMISSION SYSTEMS.

In applying these methods of compounding to the most general case of a transmission system with a long trunk line with several branch lines, the generators would be compounded for the center of distribution, and the synchronous motors on each branch line compounded also with respect to the center of distribution.

It is well known that poor regulation is usually the besetting sin of many long-distance transmission systems, and very often the only solution of the problem of getting rid of a large percentage of the power generated is to restrict the motion of the recording voltmeter needles so as to impress possible customers more favorably. Systems are in operation where there is a variation in voltage of 10 %, and very often when synchronous motors operating on the line get to surging, owing to the bad regulation, there will be a drop or rise of perhaps 20%. This sometimes makes the cost of lamp renewals as great as the cost of power. Such a system for a mixed load of lights and power must in the end be displaced by something better. On long-distance transmission systems, where the generator capacity is large compared with the load changes which are likely to occur, the pressure at the powerhouse may remain fairly constant and yet vary 10% at the receiver.

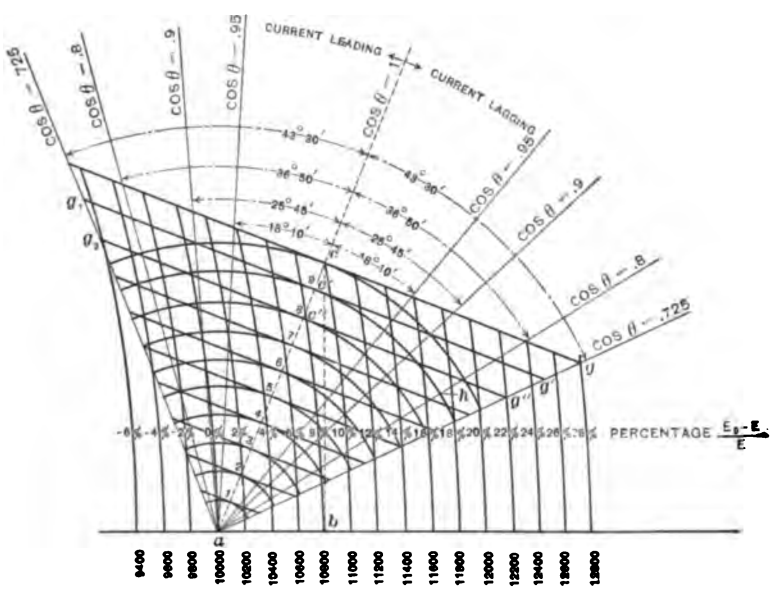


FIG. 10.—Regulation of Transmission System.

Fig. 10 and Fig. 11 bring out in a striking way the effect of changes of load and especially of changes of power factor on the regulation of the line.[1] Fig. 10 represents a 15-mile, 60 p.p.s., three-phase transmission system, with 10,000 volts between neutral and line wire. The power transmitted is 3,000 k.w. at full load, with a copper loss of 8%, including step-up and step-down transformers: *o a* is the receiver pressure, the point o not being shown. The pressure consumed over the line by the

1—A Simple Diagram Showing the Regulation of a Transmission System for Any Load and Any Power Factor. By F. G. Baum, *Elec. World and Eng.* May 18, 1901 power component of current is measured along *a c*, and the pressure consumed by the wattless current is measured at right

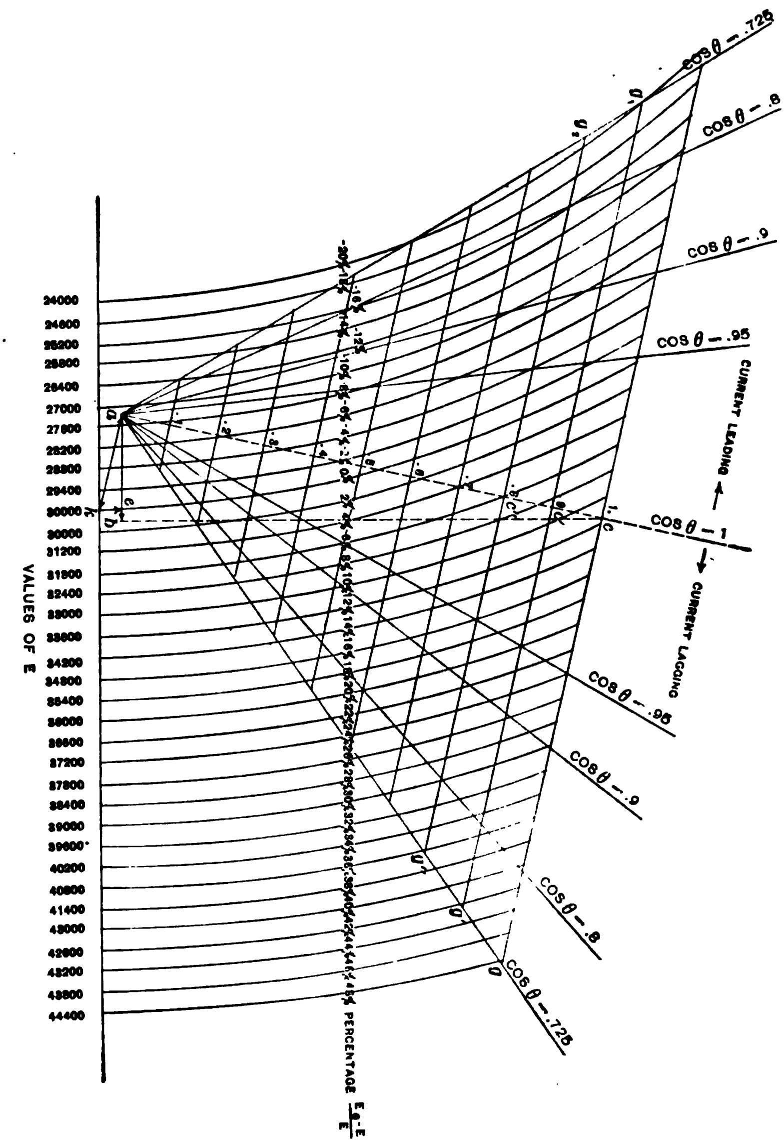


FIG. 11.—Regulation of 150-Mile Transmission Line.

angles to *a c*, to the right of *a c* for lagging currents, to the left for leading. *a c*, which represents full load, has been divided into ten equal parts, corresponding to .1, .2, etc., of full load. Through points marked .1, .2, etc., lines have been drawn at right angles to *a c*. Radial lines making angles corresponding to $\cos\ \theta = .95$, $\cos\ \theta = .9$, etc., for lagging and leading currents, have been drawn from *a*. Circular arcs, with the point *a* as center, have also been drawn through points along *a c* marked .1, .2, etc. The regulation for any load and any power factor may be determined from the figure. For example, find the regulation at .9 full load at .8 power factor: Go along *a c* to $c' = .9$, then along $c'\ g'$ to the intersection with the line $\cos\ \theta = .8$. The regulation is seen to be about 21½%. For .9 full load current, and the same power factor, the regulation is 17%, as shown by the point *h*.

Fig. 11 shows the regulation of a 150-mile, 60 p.p.s., three-phase transmission system, with 30,000 volts between neutral and outside. The power transmitted is 9,000 k.w., with a line loss of 10%, including step-up and step-down transformers. The triangle *k l a* shows the rise in pressure over the line due to the charging current. The regulation of the line for any load and any power factor is shown.

As an example find *E o* for 0.8 load at 0.725 power factor. Follow *a c* to point c'' (marked .8), then follow $c''\ g''$ to point of intersection of $c''\ g''$ with line marked $\cos\ \theta = 0.725$. The point is on the circle 40,800. This is the value of *E o* (36% above *E*). (Lagging current assumed in example, for leading current *E o* is given by *p t.* g_2).

An intelligent application of the methods here given will, it is believed, even in the worst case, give us a system with very satisfactory regulation.

I wish to thank Mr. Frank Adams, Superintendent of the Stockton Gas and Electric Company, for allowing me the privilege of making the preliminary tests on the compensator in the company's station.

STANFORD UNIVERSITY, CAL.
April, 1902.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 18th, 1902.

FORMULA FOR CALCULATING THE ELECTROMOTIVE FORCE AT ANY POINT OF A TRANSMISSION LINE FOR ALTERNATING CURRENT.

BY M. LEBLANC.

It is a recognized fact that in long-distance transmission of electrical energy by means of alternating current, the voltage has often been found to be higher at the receiving end than at the generator end of the line. This increase in voltage may be considerable, and it is important to take it into account when making installations.

We intend to establish a formula giving the voltage at any point of an alternating current transmission line. Let us call ρ, γ and λ respectively, the resistance, capacity and self-induction per unit of length of both conductors of a line of length l. Let us send into it an alternating current of frequency $\beta = \frac{m}{2\pi}$ varying as a function of the time according to a sine law. Let us call V_x the voltage at a point x located at a distance x from the generator end.

The transmission of the current is governed by the equation:

$$\frac{d^2V}{dx^2} = \gamma\lambda\frac{d^2V}{dt^2}t + \gamma\rho\frac{dV}{dt}$$

Under constant load, this equation is satisfied if we make, according to Vaschy:

$$V_x = e^{a(l-x)}\left[A\sin m\,(t - x/v) + B\cos m\,(t - x/v)\right] + e^{-a(l-x)}\left[D\sin m\,(t + x/v) + F\cos m\,(t + x/v)\right]$$

$$v = \frac{1}{\sqrt{\gamma\lambda}}\sqrt{\frac{2\lambda m}{\lambda m + \sqrt{\rho^2 + m^2\lambda^2}}}; \quad a = \tfrac{1}{2}\gamma\rho v.$$

The velocity v is the speed of transmission of the electric waves along the line.

The intensity i_x at the point x being given by the equation:

$$\rho i_x + \lambda \frac{di_x}{dt} = -\frac{dV_x}{dt}, \text{ we have:}$$

$$(2) \quad \rho i_x + \lambda \frac{di_x}{dt} = e^{a(l-x)} \left[\left(Aa - B\frac{m}{v}\right) \sin m \left(t - \frac{x}{v}\right) + \left(A\frac{m}{v} + B\, a\right) \cos m \left(t - \frac{x}{v}\right)\right] + e^{-a(l-x)} \left[\left(-D\, a + F\frac{m}{v}\right) \sin m \left(t + \frac{x}{v}\right) - \left(D\frac{m}{v} + F\, a\right) \cos m \left(t + \frac{x}{v}\right)\right]$$

Let us designate by the letter U_x the maximum value of the voltage V_x at the point x; we deduce from equation (1):

$$(3) \quad U_x = \sqrt{e^{2a(l-x)}(A^2 + B^2) + e^{-2a(l-x)}(D^2 + F^2) + 2\sqrt{(A^2 + B^2)(D^2 + F^2)} \cos 2m\left(\frac{x}{v} - u\right)}$$

by taking:

$$\text{Tang } 2mu = \frac{BD - AF}{AB + BF}$$

In order to determine the quantities A, B, D, F, we assume that the maximum value U_l of the voltage at the far end of the line is given, and that the line is closed on a conductor of resistance r and self-induction L.

Let us make $V_l = U_l \times \sin m\, t$ and $\text{tang } m\, \varphi = \frac{m\, L}{r}$

then:

$$\rho i_l + \lambda \frac{d\, i_l}{dt} = \frac{U_l}{\sqrt{r^2 + m^2 L^2}} [\rho \sin m\, (t - \varphi) + m\, \lambda \cos m\, (t - \varphi)]$$

If we write that the equations (1) and (2) are satisfied at any instant of the time, for $x = l$, we obtain the four following equations which determine A, B, D and F.

$$U_l = (A + D) \cos \frac{m\, l}{v} + (B - F) \sin \frac{m\, l}{v}$$

$$O = -(A - D)\sin\frac{m}{v} + (B + F)\cos\frac{m\,l}{v}$$

$$\frac{U_l}{\sqrt{r^2 + m^2 L^2}}(\rho\cos m\,\varphi + m\,\lambda\sin m\,\varphi) =$$

$$(A\,a - B\frac{m}{v} - Da + F\frac{m}{v})\cos\frac{m\,l}{v} + (\frac{Am}{v} + B\,a + D\frac{m}{v} + F\,a)\sin\frac{ml}{v}$$

$$\frac{U_l}{\sqrt{r^2 + m^2 L^2}}(m\,\lambda\cos m\,\varphi - \rho\sin m\,\varphi) =$$

$$(-A\,a + B\frac{m}{v} - D\,a + F\frac{m}{v})\sin\frac{m\,l}{v} + (A\frac{m}{v} + B\,a - D\frac{m}{v} - F\,a)\cos\frac{m\,l}{v}$$

If we make:

$$\frac{U_l}{\sqrt{r^2 + m^2 L^2}} = I_l\,;\ \text{Tang}\, m\,\Psi = \frac{\frac{m}{v}}{a};\ \text{Tang}\, m\,X = \frac{m\,\lambda}{\rho};$$

$$(\Psi - X) = \delta$$

As we have:

$$a^2 + \frac{m^2}{v^2} = m\,\gamma\sqrt{\rho^2 + m^2\lambda^2}$$

We can write:

$$2\,A = U_l\cos\frac{m\,l}{v} + \sqrt{\frac{\sqrt{\rho^2 + m^2\lambda^2}}{m\,\gamma}}\,I_l\cos m\left(\frac{l}{v} - \varphi - \delta\right)$$

$$2\,B = U_l\sin\frac{m\,l}{v} + \sqrt{\frac{\sqrt{\rho^2 + m^2\lambda^2}}{m\,\gamma}}\,I_l\sin m\left(\frac{l}{v} - \varphi - \delta\right)$$

$$2\,D = U_l\cos\frac{m\,l}{v} - \sqrt{\frac{\sqrt{\rho^2 + m^2\lambda^2}}{m\,\gamma}}\,I_l\cos m\left(\frac{l}{v} + \varphi + \delta\right)$$

$$2\,F = -U_l\sin\frac{m\,l}{v} + \sqrt{\frac{\sqrt{\rho^2 + m^2\lambda^2}}{m\,\gamma}}\,I_l\sin m\left(\frac{l}{v} + \varphi + \delta\right)$$

Equation (3) will be expressed as follows:

$$U_x = \tfrac{1}{2}\sqrt{\begin{aligned}&U^2_l\left(e^{2a(l-x)} + e^{-2a(l-x)} + 2\cos\frac{2m}{v}(l-x)\right) \\ &+ \frac{\sqrt{\rho^2+m^2\lambda^2}}{m\gamma} I^2_l\left[e^{2a(l-x)} + e^{-2a(l-x)} - 2\cos\frac{2m}{v}(l-x)\right] \\ &+2\sqrt{\frac{\sqrt{\rho^2+m^2\lambda^2}}{m\gamma}}\, I_l\, U_l \\ &\qquad \left[\begin{aligned}&\left(e^{2a(l-x)} - e^{-2a(l-x)}\right)\cos m(\varphi+\delta) \\ &+2\sin\frac{2m}{v}(l-x)\sin m(\varphi+\delta)\end{aligned}\right]\end{aligned}}$$

if we take:

$$\operatorname{Tang} m\,\delta = \frac{m(\rho - \lambda v a)}{m^2\lambda + \rho v a} = \frac{\rho}{m\lambda + \sqrt{\rho^2 + m^2\lambda^2}}$$

Such is the expression for the e.m.f. at the point x, located at a distance x from the generator end, when supplying to the receiving apparatus, with a power factor equal to $\cos m\,\varphi$, a current of intensity I_l, of frequency $\beta = m/2\pi$, with a voltage U_l.

Let us consider the line when operated at no load.

We have $I = O$, then the voltage U_0 becomes

$$U_0 = U_l\sqrt{\frac{e^{2al} + e^{-2al} + 2\cos\frac{2ml}{v}}{4}}$$

For a line to transmit energy efficiently, the coefficient of damping $2\,a\,l$ will be always very small, and the sum $e^{2al} + e^{-2al}$ will be approximately equal to 2.

If the line be rather long and $\cos 2\,ml/v$ differs little from unity, we have $U_l > U_0$.

This effect will be maximum when:

$$2\frac{m\,l}{v} = \pi, \text{ or } l = \tfrac{1}{4}\frac{v}{\beta}$$

Thus, the length of the line will be equal to $\frac{1}{4}$ of the length of the transmitted wave, and the ratio U_1/U_0 will be very high.

This condition will not generally occur with currents of usual frequency, but it may occur on long lines with low harmonics which will bring dangerous surgings in the voltage of the line.

Therefore, we must avoid with the utmost care the production of harmonics by the generating and receiving apparatus, and use in long distance transmission currents with frequency as low as possible, in order that the length of the line may be always very short as compared with the length of the waves transmitted.

A formula similar to the preceding may be deduced giving the intensity I_x at a given point x of the line located at a distance x from the generator end. Then we have :

$$I_x = \frac{1}{2}\sqrt{\frac{m\gamma}{\rho^2+m^2\lambda^2}}\sqrt{\begin{aligned} & U^2_l\left[e^{2a(l-x)}-e^{-2a(l-x)}-2\cos 2m\frac{l-x}{v}\right] \\ & +\frac{\sqrt{\rho^2+m^2\lambda^2}}{m\gamma}I^2_l\left[e^{2a(l-x)}+e^{-2a(l-x)}\right. \\ & \qquad\qquad \left. +2\cos 2m\frac{l-x}{v}\right] \\ & +2\sqrt{\frac{\sqrt{\rho^2+m^2\lambda^2}}{m\gamma}}I_l\,U_l \\ & \left\{\begin{aligned} & \left(e^{2a(l-x)}-e^{-2a(l-x)}\right)\cos m(\varphi-\delta) \\ & -2\sin 2m\frac{l-x}{v}\sin m(\varphi-\delta) \end{aligned}\right\} \end{aligned}}$$

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 18th, 1902.

THE NEW GENERATING PLANTS OF THE NIAGARA FALLS POWER COMPANY.

BY H. W. BUCK.

The growth of the applications of Niagara Falls power has been so rapid since the starting up of the first power-house in 1895 that the entire 50,000 h.p. of the first plant has been taken up to its limit. This growth was anticipated by the company three years ago, when the hydraulic development of a second plant was started. This plant is nearly completed and within a few months the first generator of its equipment will be performing useful work.

This power-house, from a popular standpoint, may be considered a duplicate of the old one, with which every engineer is familiar, and differs only in some of its technical details. It is located on the opposite side of the intake canal and nearer to the river, and has its water wheels placed at the bottom of its own separate wheel pit. Discharge water is led out from this pit by a branch tunnel, which after leading independently for about 600 feet, joins the main tunnel, which, as is known, has a capacity of 100,000 h.p. The new turbines are somewhat different from those in power-house No. 1, being of the internal discharge type and having the discharge water carried off through draught tubes, which add about 10% to the effective head. This increase in efficiency gives 10% more power for the same amount of water used in power-house No. 1, and in consequence the plant is laid out for 11 units of 5,000 h.p. each, instead of 10. The turbines were designed by Escher. Wyss & Co., of Zurich, and were built by the I. P. Morris Company, of Philadelphia. The

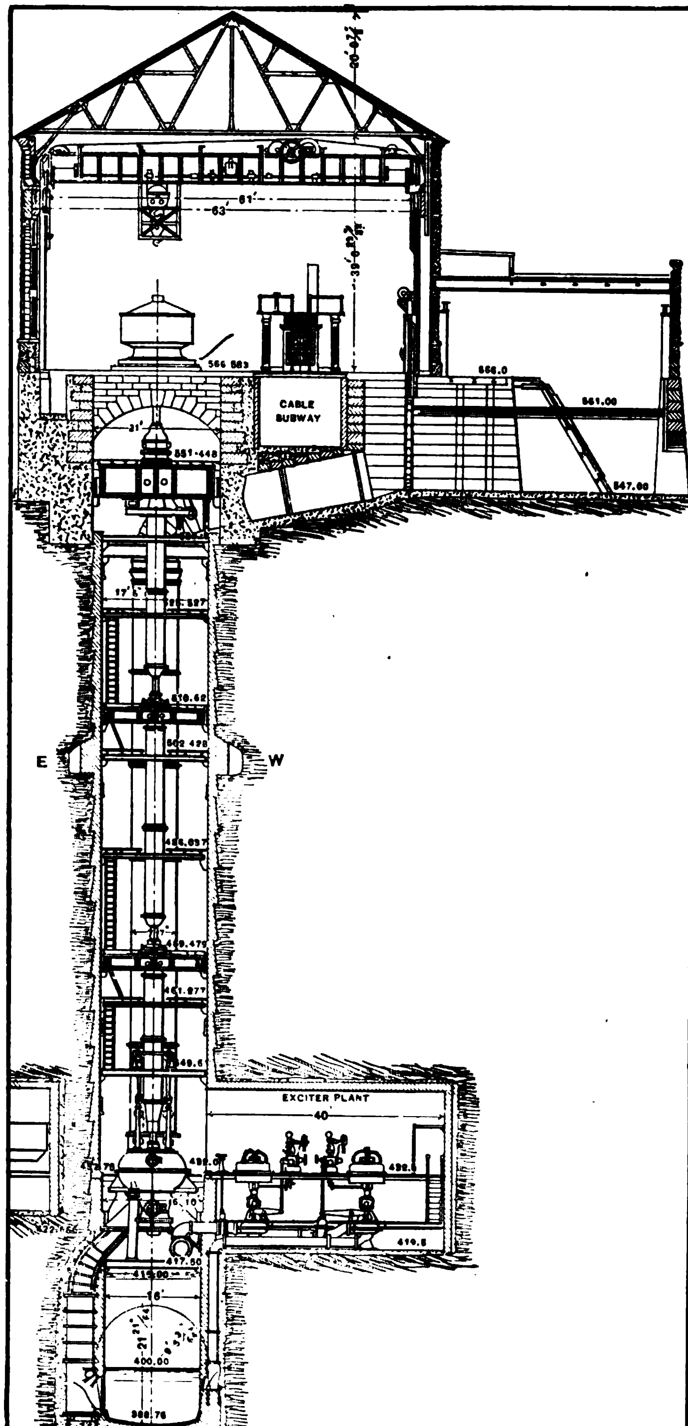


FIG. 1.—Section of Power-House No. 2.

governors were also designed by Escher, Wyss & Co., and are being built by A. Falkenau of Philadelphia. They are of the oil pump operated type and give a maximum variation of speed of about 5%, with 100% load variation, and for fractional changes in load the regulation obtained is about the same as that of a good steam engine.

The electrical equipment is furnished throughout by the General Electric Company. In general, its characteristics are the same as in the apparatus in power-house No. 1. The generators are of 5,000 h.p. each (3,750 k.w.) wound for 2,300 volts, two-phase, 25 cycles at 250 r.p.m. This type was decided upon on account of its exact interchangeability with power-house No. 1. It was considered that the advantages which might result from winding the new generators for a higher voltage, would be more than offset by the lack of interchangeability between two power-houses located so near together as to be governed by the same conditions.

Electro-technically, power-house No. 2 differs in several essential details from the installation in the old plant, the differences being due largely to the advance of the art since the time when the first power-house was equipped. The main points of difference are:

(1) Closer generator regulation, the regulation on the new machines being 10% and on the old ones about 30%.

(2) The entire plant will be operated from a single switchboard instead of two.

(3) The feeders will be protected with automatic oil circuit-breakers.

Generators.

The first six generators to be installed will be similar in outline to those in the first plant, being of the external field type, with the nickel-steel revolving magnet ring. This machine is shown in assembly in Fig. 2. In appearance the most striking difference is in the omission of the iron bridges over the machines. This omission results from the collector rings being placed at the bottom of the dynamo shaft, instead of at the top.

As stated above, the principal difference in these new generators is in the matter of regulation, the regulation being nearly three times as close. This closer regulation was adopted in order to ensure constancy of voltage on the system with variations in load, and also to reduce to a minimum the unbalancing of the voltages on the different phases caused by difference in loads upon them. These points are of great importance on such a system as that of the Niagara Falls Power Company. Many electrical distribution systems are made up of a very large number of small consumers of power and the actions of any one customer have little effect upon the voltage of the system; consequently, in such cases, regulation is not of such vital importance. But the Niagara Falls system is made up of a comparatively small number of very large consumers of power, any one of whom may, by a change in his load, cause a serious disturbance on the circuits. Furthermore, it is unique in one of its characteristics, in that much of the power is used on large single-phase electric furnaces, which take their power from one phase only. Since it is impossible to control these furnaces, so that at all times the same number shall be in operation from each of the two phases, inequality of load on the phases results and the voltages are unbalanced. This unbalancing is disastrous to polyphase synchronous and induction motors on the system, for the high voltage phase tends to carry all the load, and the windings on this phase are overloaded. These results can be rendered inappreciable only by the use of generators of close regulation.

The armature winding is a two-circuit series closed winding and consists of formed one-turn coils placed in open slots with two coils to a slot. The conductor is made up of stranded cable pressed into rectangular shapes. This stranding of the conductor reduces eddy current losses in the armature conductor itself which exist in the case of a large solid bar, as used in the old machines. The open slot is also considered an advantage in a machine of such great length of armature core, for in the closed slot it is necessary to drive the armature bar with its insulation on throughout the length of the slot in order to put it in place. The system of interlacing the end windings used in the new machines gives strong construction to withstand the displacement strains caused by short circuits.

The system of ventilation is radically different in the new machines. Referring to Fig. 2, a baffle plate will be seen between the bottom of the armature winding and the bottom of the revolving field. This forces all the air which is actuated by centrifugal pressure to enter the machine at the bottom inside of the armature shell. From here the air passes outward through the air ducts in the armature core, cooling the iron and the winding. It then continues outward radially between the layers of the field winding into an annular space at the back of the field coils and thence outward through holes in the magnet ring, which are bored in line with the pole-piece bolts. The action is that of a centrifugal blower, caused by the rotation of the field poles and ring. Some of the air also passes outward at the top of the ring through ventilating holes provided for the purpose. The operation of the air system is very satisfactory, and the blast of air secured is tremendous. From tests which have

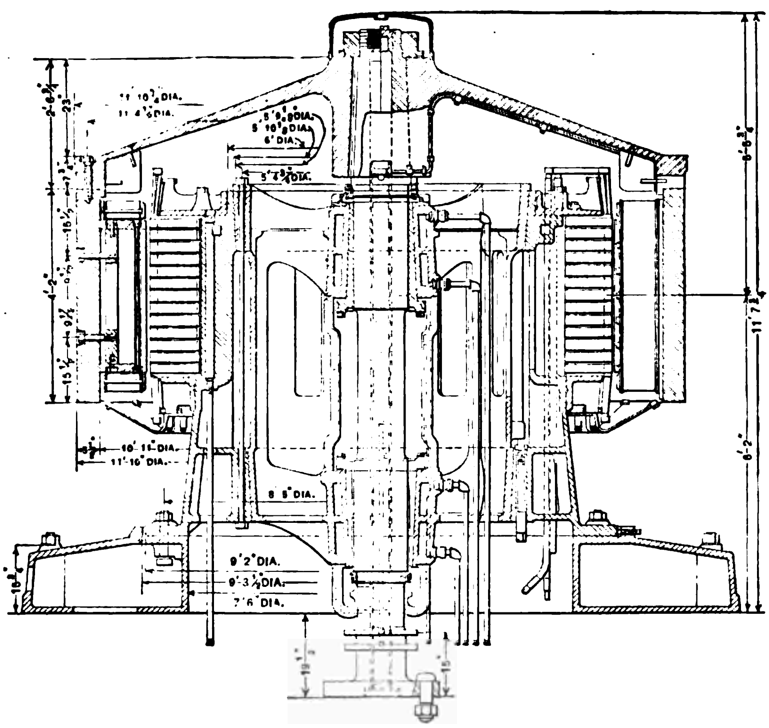


FIG. 2.—External Field 5000 H. P. Generator, Power-House No. 2.

thus far been made, it is believed that these machines will run from 10° to 15° cooler than the old ones. These improvements in design were introduced by Mr. W. L. R. Emmet of the General Electric Company, with the coöperation of Mr. H. G. Reist.

The generator equipment in this power-house is completed with five 5,000 h.p. machines of the internal revolving field type shown in Fig. 3. It was decided that the last five machines of the installation should be of this type on account of the much lower cost of building, simplicity of handling and accessibility to the various parts, as compared with the external field design. These machines are also wound for 2,300 volts, 25 cycles, two-phase and operate at a speed of 250 r.p.m.

These machines will have the same regulation as the first six installed, and in other respects the electrical constants will be the same. From the drawing in Fig. 3, the construction may be clearly seen. It is similar to the standard horizontal shaft engine-driven alternators of well-known types, and its

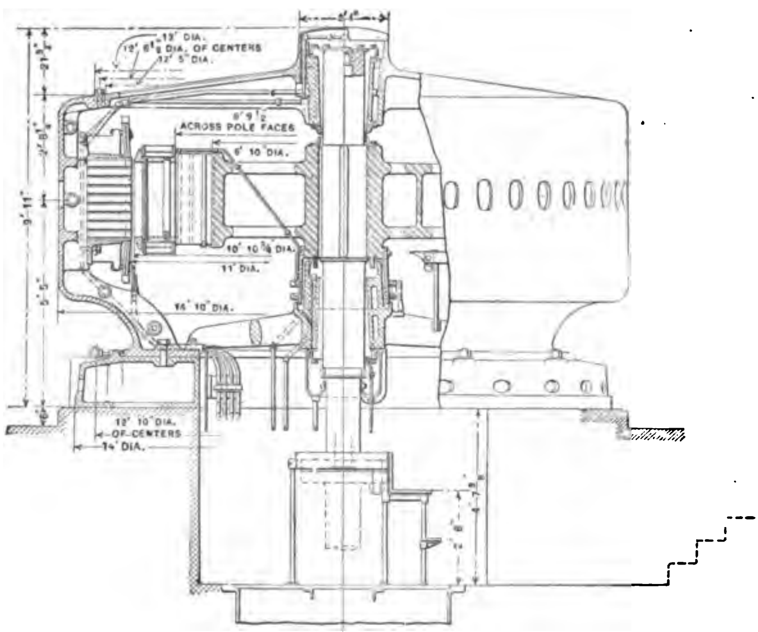


Fig. 3—Internal Field 5000 H. P. Generator, Power-House No. 2.

method of ventilation is the same. Recent improvements in the mechanical construction of generators have made this type possible at the high speed of 250 r.p.m. and improvements in water-wheel governors have made permissible the lower fly-wheel effect incident to this design, and the consequent omission of the nickel-steel ring of the first machines.

In the two power-houses, then, there will be three types of generator, but no trouble is expected in operating all the machines in parallel. As is well-known, when two alternators of different regulation operate in parallel, the resultant regulation is the mean between the two. Idle current between the two types may be prevented by careful adjustment of the field currents.

The guaranteed efficiency of the external field generators was;

Full load.................................98%

¾ load 97.3%

½ load 96%

From actual test, the full load efficiency has come out 98.15%, which is probably the highest ever attained in an electrical generator.

EXCITER PLANT.

The exciter plant in the new power-house will be quite different in arrangement from the old one. The installation will be made complete with the exciter switchboard in a compartment recessed into the rock at the bottom of the main wheel-pit, as shown in Fig. 1. This position will eliminate the long shaft necessary with exciters placed on the main dynamo floor and will simplify the operation of the plant. The equipment will consist of four 150 k.w.compound wound, vertical shaft, 220 volt exciters each coupled to an independent turbine, placed directly underneath. The speed is 750 r.p.m., and each exciter turbine is controlled by a separate governor. The exciter plant wiring diagram is shown in Fig. 8. It will be seen that the power-house lights and auxiliary motors will be operated from this plant. A panel is also provided for interconnection with the exciter plant in power-house No. 1. The double set of bus-bars permits of the separation of exciting circuits and lights and motors. The exciter compartment will be directly connected by telephone with the main generator switchboard.

MAIN SWITCHBOARD.

As in all plants, the most important element for successful operation is the layout of the switchboard apparatus. The switchboard in power-house No. 2 has been carefully considered and is believed to be convenient and as simple as it can be made and still accomplish the desired results. There has been a tendency in the design of some of the recent large switchboards, toward complexity and the installation of unessential appliances which by their presence cause more trouble and confusion *per se* than that which they are intended to prevent. This has been avoided as far as possible in the design of this board.

Fig. 4 shows a plan of the power-house floor and the relative positions of generators, switchboard gallery, oil switches and

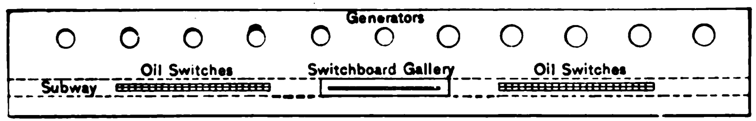
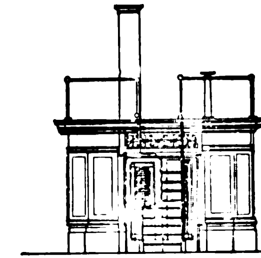


FIG. 4.—Floor Plan of Power-House No. 2.



END ELEVATION

FIG. 5a.

FRONT ELEVATION

FIG. 5.—Main Switchboard of Power-House No. 2,

cable subway. Fig. 6 shows a section through the oil switches and cable subway and indicates the location of the bus-bars placed in fireproof compartments. Fig. 5 shows a front elevation of the main switchboard gallery and controlling panels. In respect to switching, the power-house is divided into two parts, one of six generators and one of five. Each part has its own group of oil switches and its double set of bus-bars. Fig. 10 shows the relations between the two groups and also the inter-

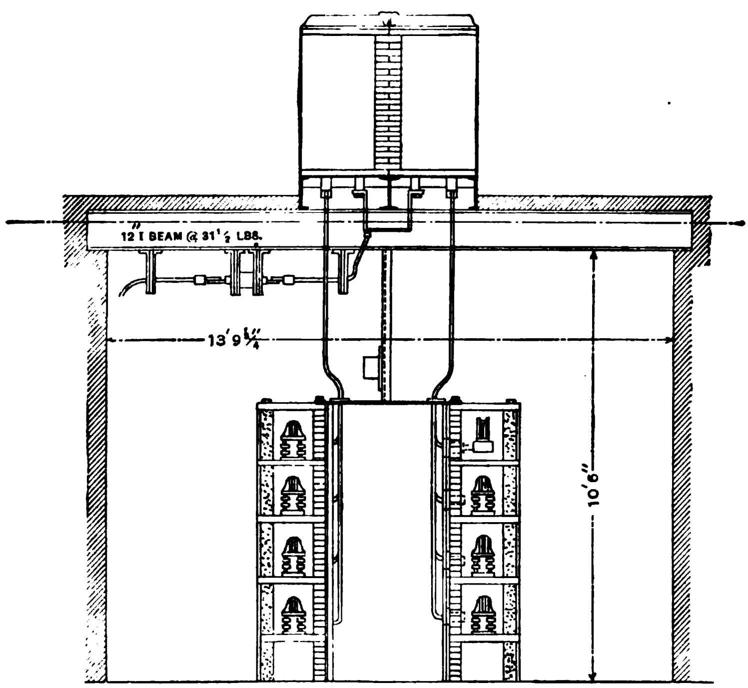


FIG. 6.—Section through Cable Subway under Oil Switches showing Bus-Bars, etc.

connections with power-house No. 1. All the switches in the new power-house are the General Electric electrically operated oil break type of the well-known design. This switch is shown in Fig. 7. All cables are led through the cable subway. They are heavily insulated with rubber, covered with a fireproof braid and supported on brackets with porcelain clamp insulators.

The main switchboard consists of a gallery in the center of the building, having mounted on it 36 separate controlling panels:

11 generator, 22 feeder, 2 interconnecting and 1 exciter panel. The relative location of these panels may be seen in Fig. 5, together with their equipment. All the switching is done on these panels by means of relay switches, placed in distinctive relation to one another and in such a relation to imitation bus-bars placed throughout the face of the switchboard, that the connecttions are clearly indicated and no mistake in switching can easily

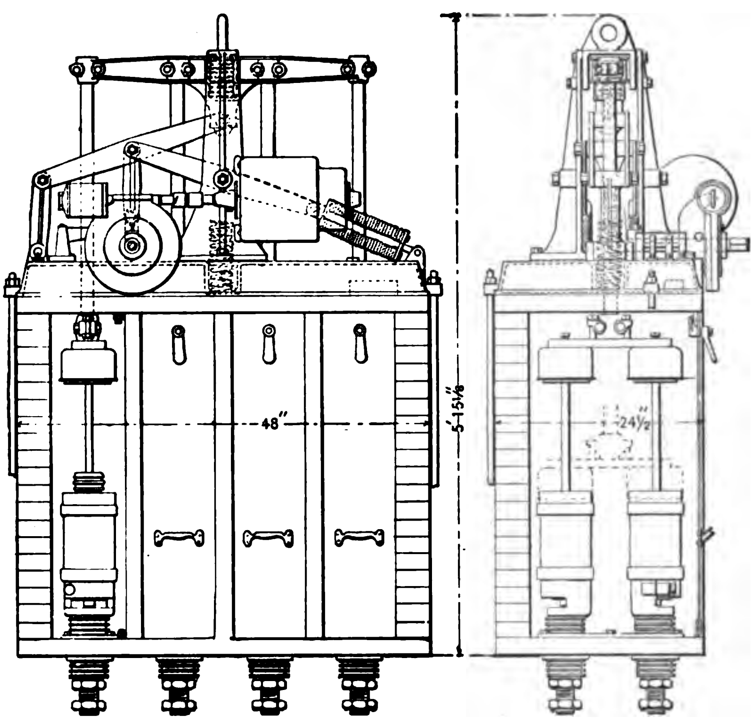


FIG. 7.—2200 volt, 2-Phase Electrically operated Circuit-Breaker, Power-House No. 2.

be made. On the generator panels are two selector relay switches and one generator relay switch; on the feeder panels are two relay selector switches, and on the interconnecting panels are relay interconnecting switches, for making the various connections between the two groups in the new power-house and between the two power-houses. On the sub-bases of the generator panels are dummy exciter bus-bars, with relay double-throw generator field switches. All these relay switches operate electrically the real switches on the power-house floor and have the exact relation to the dummy bus-bars which the real switches have to the real bus-bars, so that even a green man could hardly make a mistake in throwing a switch. Return indicators are placed adjacent to the relay switches, so that the operator may tell at once whether the real switch has responded correctly to the movement of the relay.

There has been a considerable craze during the last few years for the operation of switchboard apparatus by bench-board control, but in designing the board for this plant, the bench-board system, although carefully considered, was rejected as inconvenient. In the bench-board system, the operator in switching must first go to the bench-board and pick out the relay switch in question, then taking his eye off the switch, he must pick out from a concentrated mass of instruments in front of him on entirely separate panels, the instruments involved in the movement which he is about to make. This is not altogether convenient, and there is always a chance of a mistake. It is believed that the advantages of this bench-board system are more imaginary than real.

In the switchboard installed in this plant, each panel is a complete unit, and comprises all the apparatus, both switches and instruments, which are necessary for any operation which may be made upon it, so that when the operator goes to a feeder or a generator panel he has before him, enclosed within the limits of the particular panel, all the apparatus with which he is concerned at the time. All synchronizing will be done by means of a Lincoln synchronizer placed upon a swivel on the top of the switchboard.

The generator field rheostats and field switches are located under the main switchboard gallery. All feeders are equipped with recording wattmeters installed in the basement of the new office building, through which the outgoing feeders pass at the end of the cable subway.

It is the intention to operate the 21 generators normally in four independent groups, but the interconnections are so arranged that they may all be operated in parallel if desired, or any one generator may be thrown on any group. These connections are indicated in Fig. 10.

The feeder circuit-breakers will be operated by time-limit relays having an attachment devised by Mr. W. K. Gibboney of the Power Company. A time-limit relay is a useful device for preventing a circuit-breaker from opening unnecessarily at times of momentary overloads, but if a real short-circuit occurs, it is objectionable. Experience has shown that on a system like that at Niagara, where there is a large amount of syn-

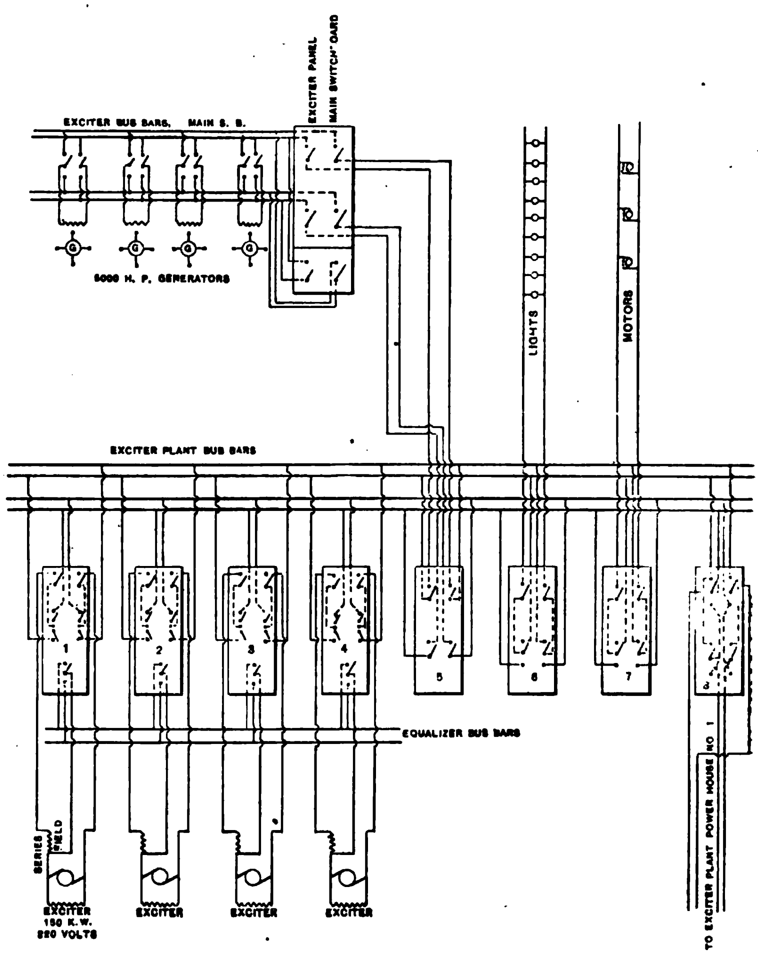


FIG. 8.—Wiring Diagram, Exciter Plant Power-House No 2.

chronous apparatus in operation, if a short-circuit occurs it must be disconnected at once, or else the prolonged drop in voltage will cause all of the synchronous apparatus to drop out of step; whereas, if the short-circuit can be disconnected instantly, the inertia of the rotating parts of the synchronous apparatus will keep them in step for this short period. For this reason, the ordinary time-limit relay is objectionable, since it causes a delay. The device referred to above consists of a dash-pot attachment to the tripping plunger of the circuit-breaker. This retards the movement of the plunger and consequently the opening of the breaker for ordinary temporary overloads, but if a real short-circuit occurs,the pull on the plunger is so strong that the dash-pot has no effect and the circuit-breaker opens instantly.

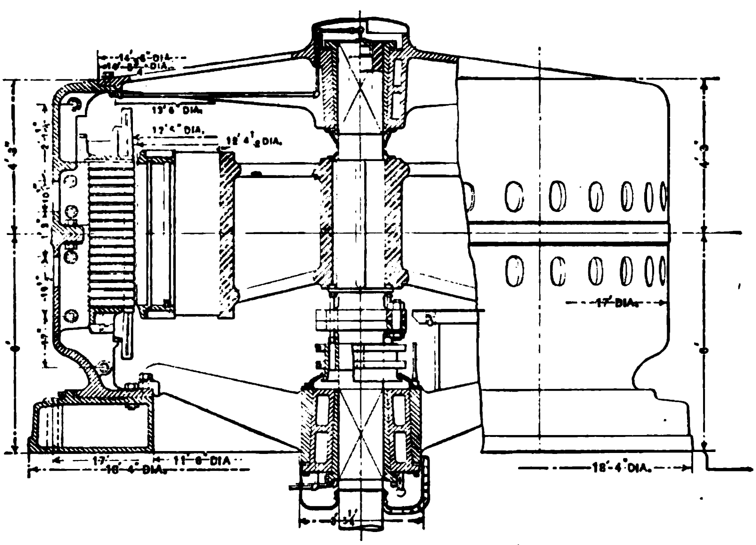


FIG. 9.—10 000-H.P., 12.000-Volt, 3-Phase Generator, Canadian Power-House.

THE CANADIAN PLANT.

Anticipating still further increase in the use of Niagara power, the Niagara Falls Power Company has, through its allied company, the Canadian Niagara Power Company, started work on its plant on the Canadian side of the Falls. This plant will be located in the Victoria Park about 1,500 feet above the Horse Shoe Falls. Its hydraulic feature will be similar to the American plants, with its intake canal, wheel-pit and discharge tunnel leading to the foot of the Horse Shoe Falls. This power development will be used for the transmission of power to Toronto and other Canadian cities within transmission distance, and for the distribution of power to factories located in Canada in the neighborhood of the power-house. It will also be used for the supply of power to the American power system, with which it will be arranged to operate in parallel.

The essential difference embodied in this plant will be in the size of unit and in the electrical arrangements. The unit will be of 10,000 h.p. capacity (7,500 k.w.), and the generators will be wound for 12,000 volts three-phase. The frequency will be retained at 25 cycles for the sake of uniformity with the American plants, so as to permit of parallel operation. In selecting this size of unit the American and Canadian systems were regarded as one. Since this is likely to ultimately reach an output of several hundred thousand horse power, a unit of 10,000

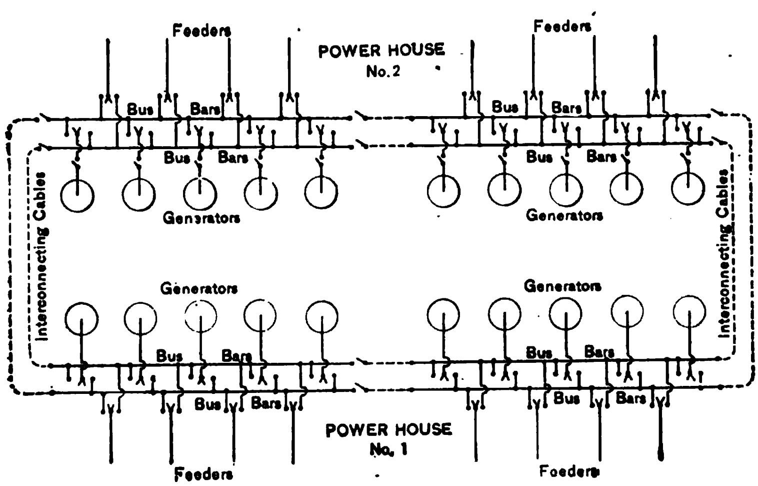


FIG. 10.—Showing Interconnection between American Power-Houses.

h. p. is not a large proportion of the whole and is not too large an amount of power to concentrate in one machine from the standpoint of convenience.

The principal advantage of a unit of this size over the smaller one is in the reduction in cost of development per h.p. This reduction in cost results from

(1) Lower cost of generator per h.p.

(2) Lower cost of turbines per h.p.

(3) A 10,000 h.p. unit occupies only slightly more space than one of 5,000 h.p. capacity which results, for a given plant output, in great reduction in length of wheel-pit, power-house and forebay and a consequent reduction in construction.

Other advantages will result, such as simplicity of operation, owing to the reduction in the number of units and reduction in the cost of maintenance. This size of unit was suggested by the engineers of the Niagara Falls Power Company and was adopted upon their recommendation. The generators, three of which

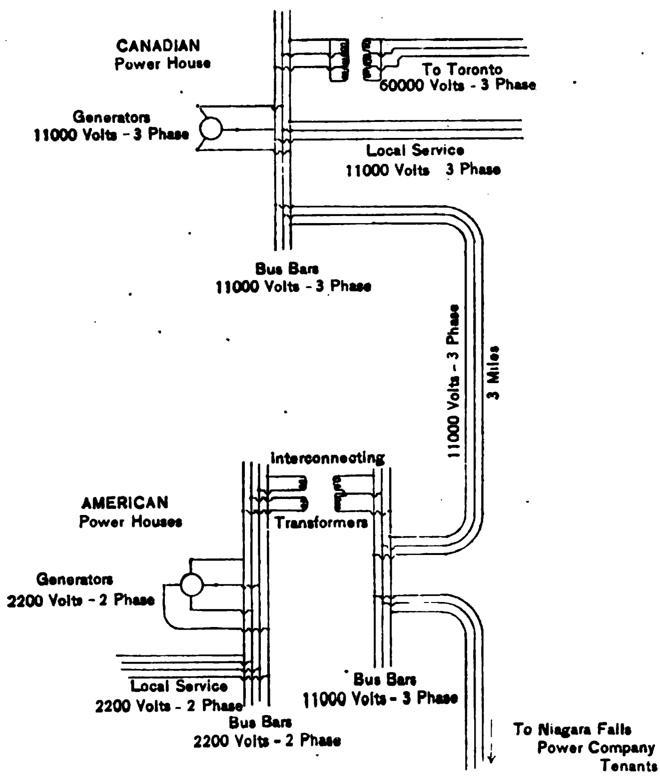


FIG. 11.—Method of Interconnecting American and Canadian Power Systems

have been ordered, are being constructed by the General Electric Company.

This generator is shown in assembly in Fig. 9. It is of the internal revolving-field vertical shaft type. Its revolving-field ring is built up of punched laminations bolted together with joints lapped. This method of construction gives a uniform and definite strength of ring and high magnetic permeability. On account of the high speed, 250 r.p.m., the generator is very small as compared with some of the large engine-driven units, its over-all diameter being only about 19 feet. The weight of the revolving part of the machine is 141,000 lbs., with a fly-wheel effect at 250 r.p.m. of 2,000,000,000.

The generators are wound directly for 12,000 volts three-phase instead of 2,300 volts two-phase, as in the American plants. This high voltage was selected, not for long-distance transmission, but for economy in distribution to power users near the power-house. In distributing large amounts of power underground from a 2,300 volt, two-phase plant, after a radius of about one mile is exceeded, it becomes cheaper to transform to 12,000 volts three-phase and distribute at this voltage than to supply power directly at 2,300 volts. From this it becomes evident that great economy results from the direct generation of the higher voltage. For long-distance transmission, step-up transformers will be used to raise the voltage to 22,000, 40,000 or 60,000 volts.

Fig. 11 shows the method which will be adopted for operating in parallel the American and Canadian systems. The connection will be made by triple conductor cables carried across the upper arch bridge over the Niagara Gorge. The paralleling will be done through step-down Scott connected transformers, as shown.

The switchboard and auxiliaries have not yet been decided upon for this power-house. It is not expected that it will be in operation for a year or eighteen months.

NIAGARA FALLS, June 6, 1902.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 18th. 1902.

NOTES ON THE THEORY OF THE SYNCHRONOUS MOTOR,

WITH SPECIAL REFERENCE TO THE PHENOMENON OF SURGING.

BY CHARLES PROTEUS STEINMETZ.

I.

While an induction motor at constant impressed voltage is fully determined as regards current, power factor, efficiency, etc., by one independent variable, the load or output, in the synchronous motor two independent variables exist, load and field excitation. That is, at constant impressed voltage the current, power factor, etc., of a synchronous motor may at the same power output be varied over a wide range by varying the field excitation, that is, the counter e.m.f. or "nominal induced e.m.f." Hence the synchronous motor may be utilized to fulfill two independent functions, to carry a certain load and to produce a certain wattless current, lagging by under-excitation, leading by over-excitation. Synchronous motors are, therefore, to a considerable extent used to control the phase relation and thereby the voltage, in addition to producing mechanical power. The same applies to synchronous converters.

With given impressed e.m.f., field excitation or counter e.m.f. corresponding thereto, and load, determine by the usual theory all the quantities of the synchronous motor, as current, power factor, etc. Thus, if in diagram Fig. 1, $\overline{OE} = e$ = e.m.f. consumed by the counter e.m.f. of the synchronous motor as corresponding to its field excitation, and if P_0 = output of motor (exclusive of friction and core loss and, if the exciter is driven by the motor, power consumed by the exciter), $i_1 = P_0/e =$

energy component of current, represented by $\overline{O I_1}$, and the current vector therefore must terminate on a line i perpendicular to $\overline{O I_1}$. If, then, r = resistance and x = reactance of the circuit between counter e.m.f. e and impressed e.m.f. e_0, $\overline{O E_r}$ = $i_1 r$ = e.m.f. consumed by resistance, $\overline{O E_x}$ = $i_1 x$ = e.m.f. consumed by reactance of the energy current i_1, hence $\overline{O E'_1}$ = e.m.f. consumed by impedance of the energy current i_1, and the impedance voltage of the total current lies on the perpendicular e^1 on $\overline{O E_1^1}$. Producing $\overline{O E_1} = \overline{O E}$, and drawing an arc with the impressed e.m.f. e_0 as radius and E_1 as center, the point of intersection with e^1 gives the impedance voltage $\overline{O E^1}$, and corresponding thereto the current $\overline{O I} = i$; and completing the parallelogram $O\ E\ E_0\ E^1$ gives the impressed e.m.f. $\overline{O E_0}$.

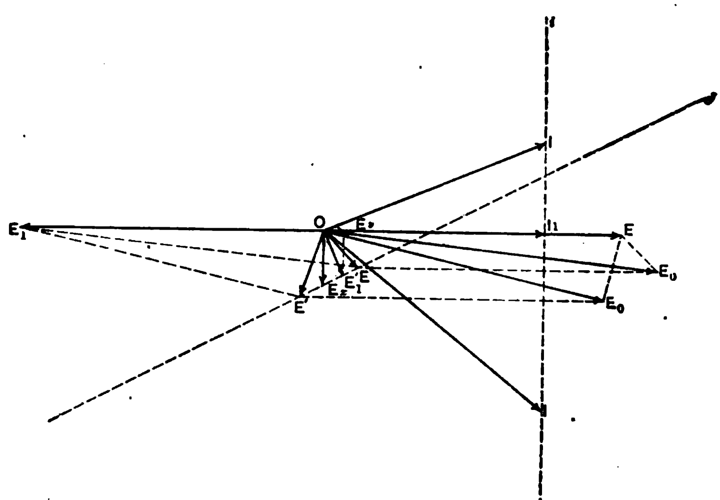


FIG. 1

Hence, by impressed e.m.f. e_0, counter e.m.f. e, and load P, the polar diagram is determined, and thereby the vectors $\overline{O I}$ = current, $\overline{O E_0}$ = impressed e.m.f., $\overline{O E}$ = counter e.m.f., and their phase relation.

Or, in symbolic representation, let:

$E_0 = e_0^1 + j\, e_0''$ = impressed e.m.f.; $e_0 = \sqrt{e_0'^2 + e_0''^2}$ (1)

$E = e' + j\, e''$ = e.m.f. consumed by counter e.m.f.; $e = \sqrt{e'^2 + e''^2}$ (2)

$I = i$ = current, assumed as zero vector.

$Z = r - j\, x$ = impedance of circuit between e_0 and e.

Z is the synchronous impedance of the motor, if e_0 is its terminal voltage. It is the impedance of transmission line with transformers and motor, if e_0 is terminal voltage of generator, and Z is synchronous impedance of motor and generator, plus impedance of line and transformer, if e_0 is the nominal induced e.m.f. of the generator (corresponding to its field excitation).

It is, then:

$$E_0 = E + i Z \tag{3}$$

or:

$$e_0' + j e_0'' = e' + j e'' + i r - j i x \tag{4}$$

and, resolved:

$$\begin{cases} e_0' = e' + i r & (5) \\ e_0'' = e'' - i x & (6) \end{cases}$$

The power output of the motor (inclusive of friction and core loss, and, if the exciter is driven by the motor, power consumed by exciter) is current times energy component of induced e.m.f., or:

$$P_0 = e' i \tag{7}$$

Hence, the calculation of the motor, from power output P_0, occurs by the equation:

Chosen: i = current.

$$\begin{array}{lll} (7) & e' & = P_0 / i \\ (5) & e_0' & = e' + i r \\ (1) & e_0'' & = \pm \sqrt{e_0^2 - e_0'^2} \\ (6) & e'' & = e_0'' + i x \\ (2) & e & = \sqrt{e'^2 + e''^2} \end{array}$$

That is, at given power P_0, to every value of current i correspond two values of the counter e.m.f. e (and hence the field excitation).

For illustration are plotted in Fig. 2, curves giving the current i as function of the counter e.m.f. e, at constant power P_0, the so-called "synchronous motor phase characteristics," for the values:

$$e_0 = 2{,}200 \text{ volts}$$

$$Z = 1 - 4 j \text{ ohms}$$

and; $P_0 = 20, 200, 400, 600, 800, 1{,}000$ k.w. output.

The five equations of the synchronous motor:

$$(1) \quad e_0^2 = e_0'^2 + e_0''^2$$

$$(2) \quad e^2 = e'^2 + e''^2$$

$$(7) \quad P_0 = e' i$$

$$(5) \quad e_0' = e' + i r$$

$$(6) \quad e_0'' = e'' - i x$$

determine the five quantities: e_0', e_0'', e', e'', e, as functions of P_0 and i.

The condition of zero phase displacement, or unity power factor at the impressed e.m.f. e_0, is:

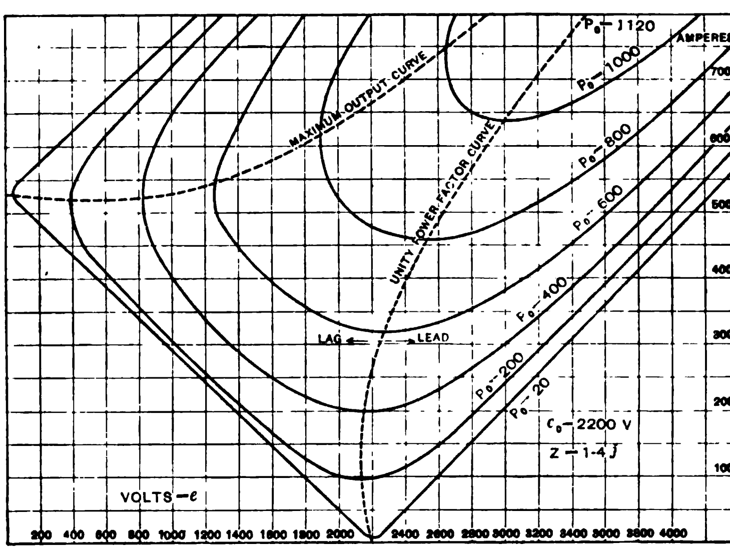


FIG. 2.

$$e_0'' = 0$$

hence:

$$e_0' = e_0, \text{ and}$$

$$(6) \quad e'' = i x$$

$$(5) \quad e' = e_0 - i r$$

hence:

$$e^2 = (e_0 - i r)^2 + i^2 x^2 \qquad (8)$$

a quadratic equation, the hyperbola of unity power factor, shown as dotted line in Fig. 2.

In this case, the power is found by substituting $e' = e_0 - i\,r$ in $P_0 = e'\,i$, as:

$$P_0 = e_0\,i - i^2\,r \qquad (9)$$

or:

$$i = \frac{e_0}{2\,r}\left\{1 \pm \sqrt{1 - \frac{4\,r\,P_0}{e_0^2}}\right\} \qquad (10)$$

As maximum output of the synchronous motor follows herefrom:

$$\sqrt{1 - \frac{4\,r\,P_0}{e_0^2}} = 0$$

in above instance:

$$P_0 = 1{,}210 \text{ k.w. at: } i = 1{,}100 \text{ amps.}$$

The curve of unity power factor (8) divides the synchronous motor phase characteristics into two sections, one, for lower e, with lagging, the other with leading current.

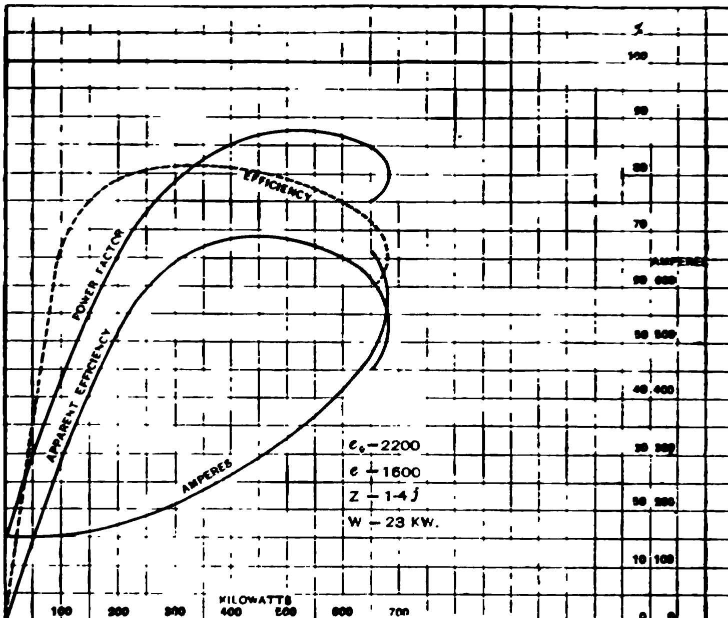
The study of these phase characteristics, Fig. 2, gives the best insight into the behavior of the synchronous motor under conditions of steady operation.

Of special interest are the load curves of the synchronous motor, or curves giving, at constant excitation: e = constant, the current, power factor, efficiency and apparent efficiency as function of the load or output $P = P_0 -$ (friction + core loss + excitation). Such load curves are represented in Figs. 3, 4, 5, 6, 7 for e = 1,600, 2,800, 2,000, 2,400, 2,180 volts. They are derived from Fig. 2 as the intersection of the curves P_0 = constant with the vertical lines e = constant.

Hence, while an induction motor has one load curve only, a synchronous motor has an infinite series of load curves, depending upon the value of e.

As seen, for low values of e (e = 1,600, under excitation, Fig. 3), the load curves are similar to those of an induction motor. The current is lagging, the power factor rises from a low initial value to a maximum, and then falls again. With increasing excitation (e = 2,000, Fig. 5) the power factor curve rises to values beyond those available in induction motors, approaches and ultimately touches unity, and with still higher excitation (e = 2,180, Fig. 7) two points of unity power factor exist, at P = 20 and P = 450 k.w. output, which are separated by a range with leading current, while at very low and very high load

Fig. 3.


EFFICIENCY
POWER FACTOR
APPARENT EFFICIENCY
AMPERES
e_0 — 2200
e — 1600
Z — 1-4 j
W — 23 KW.
KILOWATTS
100
200
300
400
500
600
700
AMPERES

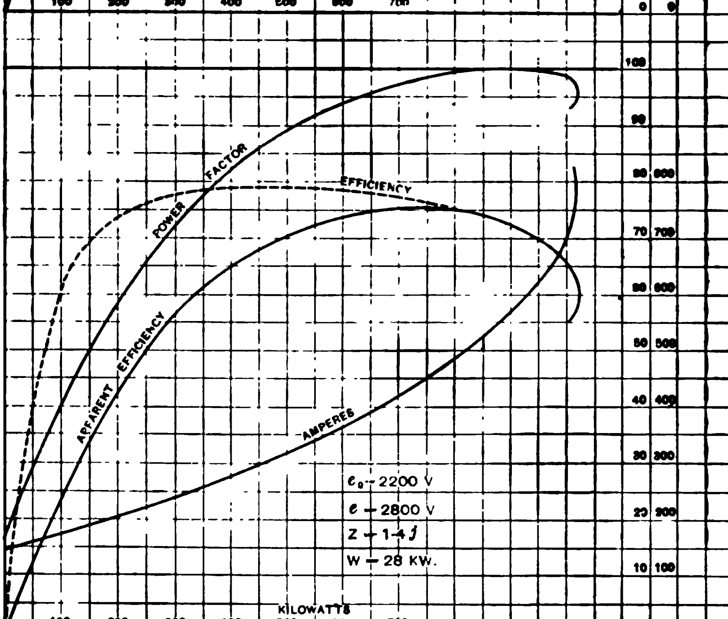

POWER FACTOR
EFFICIENCY
APPARENT EFFICIENCY
AMPERES
e_0 — 2200 V
e — 2800 V
Z — 1-4 j
W — 28 KW.
KILOWATTS
100
200
300
400
500
600
700
800
900
1000

Fig. 4.

the current is lagging. The first point of unity power factor moves toward $P = O$, and then disappears, that is, the current becomes leading already at no load, and the second point of unity power factor moves with increasing excitation toward higher loads, from $P = 450$ k.w at $e = 2{,}180$ in Fig. 7, to $P =$ 700 k.w. at $e = 2{,}400$ and $P = 900$ k.w. at $e = 2{,}800$, while the power factor and thereby the apparent efficiency decrease at light loads. The maximum output increases with the increase of excitation and almost proportionally thereto.

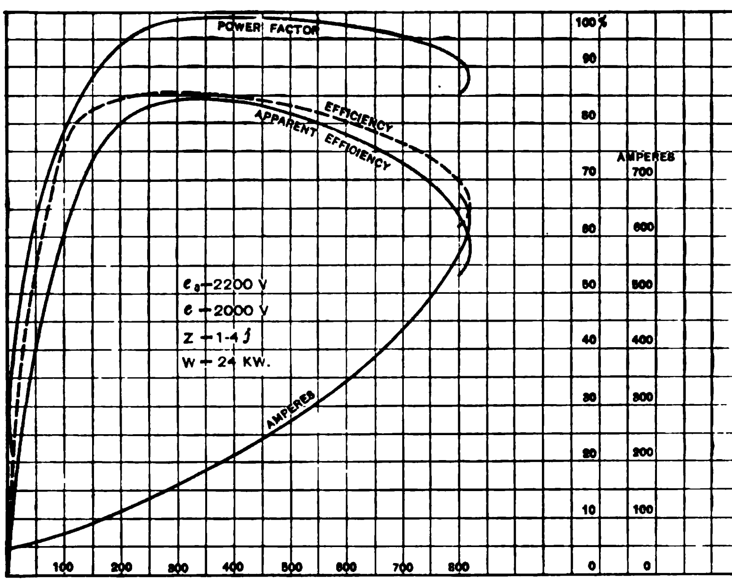


FIG. 5.

It is interesting that at $e = 2{,}180$, the power factor is practically unity over the whole range of load up to near the maximum output. It is shown once more in Fig. 7 with increased scale of the ordinates. A synchronous motor at constant excitation can, therefore, give practically unity power factor for all loads.

The resistance $r = 1$ ohm is assumed so as to represent a synchronous motor inclusive of transmission line, with about 9% loss of energy in the line at 400 k.w. output.

The friction and core losses are assumed as 20 k. w., the excitation as 4 k.w. at $e = 2{,}000$.

Considering the intersections of a horizontal line with the constant power curves of Fig. 2, gives the characteristic curves of the synchronous motor when operating on constant current. Such curves are shown for $i = 300$ in Fig. 8. They illustrate that at the same impressed voltage with the same current input, the power output of the synchronous motor may vary over a wide range, and also that for each value of power output two points exist, one with lagging, the other with leading current.

As regards phase characteristics and load characteristics, the same applies to the synchronous converter as to the synchronous motor, except that in the former the continuous cur-

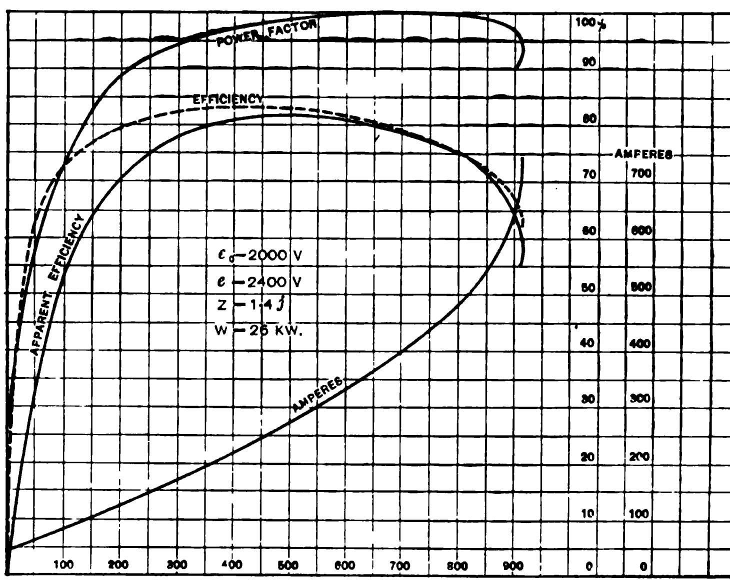


FIG. 6.

rent output affords a means of automatically varying the excitation with the load.

II.

In the preceding theory of the synchronous motor the assumption has been made that the mechanical output of the motor equals the power developed by it. This is the case only if the motor runs at constant speed. If, however, it accelerates, the power input is greater, if it decelerates, less than the power output, by the power stored in and returned by the momentum. Obviously, the motor can neither constantly accelerate nor decelerate, without breaking out of synchronism, since the counter e.m.f. e must remain within a quarter wave of the impressed e.m.f. e_0, assuming the latter as of constant frequency.

If, for instance, at a certain moment the power produced by the motor exceeds the mechanical load (as, for instance, in the moment of throwing off a part of the load), the excess power is

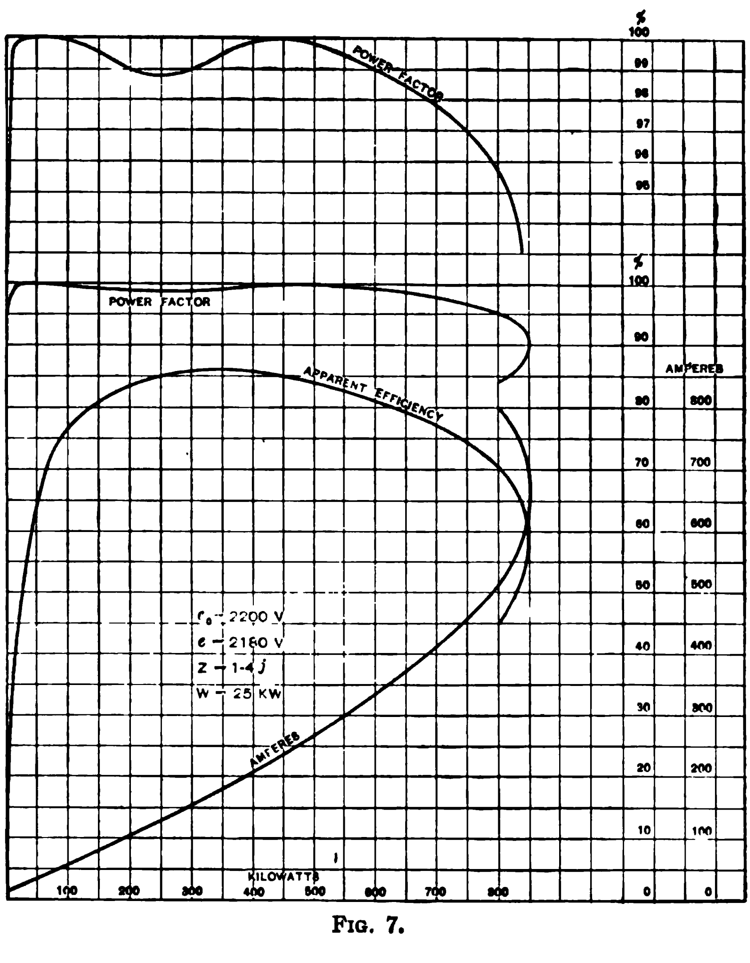


FIG. 7.

consumed by the momentum as acceleration, causing an increase of speed. The result thereof is that the phase of the counter e.m.f. e is not constant, but the vector e (in Fig. 1) moves backward to earlier time, or counter-clockwise, at a rate depending upon the momentum Thereby the current changes and the power developed changes and decreases. As soon as the power produced equals the load, the acceleration ceases, but the vector e still being in motion, due to the increased speed, further reduces the power, causing a retardation and thereby a decrease of speed, at a rate depending upon the mechanical

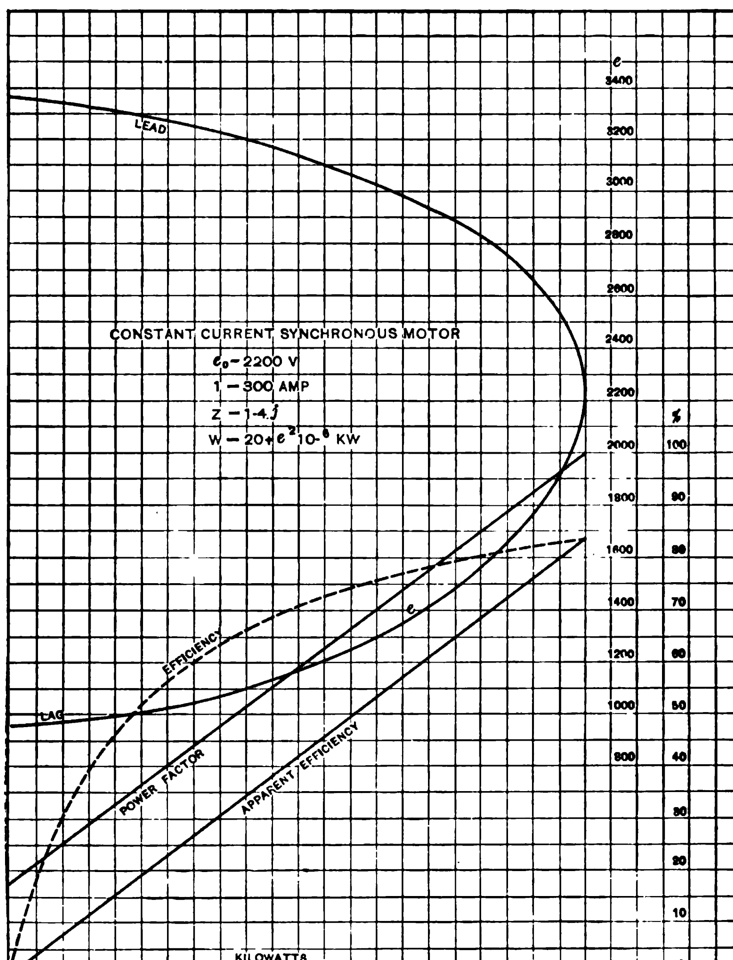


FIG. 8.

momentum. In this manner a periodic variation of the phase relation between e and e_0, and corresponding variation of speed and current occurs, of an amplitude and period depending upon the circuit conditions and the mechanical momentum.

If the amplitude of this pulsation has a positive decrement, that is, is decreasing, the motor assumes after a while a constant position of e regarding e_0, that is to say, its speed becomes uniform. If, however, the decrement of the pulsation is negative, an infinitely small pulsation will continuously increase in amplitude, until the motor is thrown out of step,or the decrement becomes zero, by the power consumed by forces opposing the pulsation, as anti-surging devices. If the decrement is zero, a pulsation started once will continue indefinitely at constant amplitude. This phenomenon, a surging by what may be called electromechanical resonance, must be taken into consideration in a complete theory of the synchronous motor.

Let:

$E_0 = e_0$ = impressed e.m.f., assumed as zero vector.

$E = e(\cos\beta + j\sin\beta)$ = e.m.f. consumed by counter e.m.f. of motor where β = phase angle between E_0 and E.

Let:

$Z = r - jx$, $z = \sqrt{r^2 + x^2}$ = impedance of circuit between E_0 and E, and: $\tan a = x/r$

The current in the system is:

$$I_0 = \frac{e_0 - E}{z} = \frac{e_0 - e\cos\beta - j\,e\sin\beta}{r - jx}$$

$$= (1/z)\,\{[e_0\cos a - e\cos(a+\beta)] + j\,[e_0\sin a - e\sin(a+\beta)]\} \qquad (11)$$

The power developed by the synchronous motor is:

$$P_0 = [E\,I]^1$$

$$= (e/z)\,\{[\cos\beta\,[e_0\cos a - e\cos(a+\beta)] + \sin\beta\,[e_0\sin a - e\sin(a+\beta)]\}$$

$$= (e/z)\,\{[e_0\cos(a-\beta) - e\cos a]\} \qquad (12)$$

If, now, a pulsaton of the synchronous motor occurs, resulting in a change of the phase relation β between the counter e.m.f. e and the impressed e.m.f. e_0 (the latter being of constant frequency, thus constant phase), by an angle δ ,where δ is a periodic function of time, of a frequency very low compared with the impressed frequency, then the phase angle of the counter e.m.f. e is: $\beta + \delta$; and the counter e.m.f. is:

$$E = e\,\{\cos(\beta+\delta)+j\sin(\beta+\delta)\}$$

hence the current:

$$I = (1/z)\,\{[e_0\cos a - e\cos(a+\beta+\delta)] + j\,[e_0\sin a - e\sin(a+\beta+\delta)]\}$$

$$= I_0 + \frac{2\,e}{z}\sin\frac{\delta}{2}\left\{\sin\left(a+\beta+\frac{\delta}{2}\right) - j\cos\left(d+\beta+\frac{\delta}{2}\right)\right\} \qquad (13)$$

the power:

$$P = e/z\,\{e_0\cos(a-\beta-\delta) - e\cos a\}$$

$$= P_0 + \frac{2\,e\,e_0}{z}\sin\frac{\delta}{2}\sin\left(a-\beta-\frac{\delta}{2}\right) \qquad (14)$$

Let now:

v_0 = mean velocity (linear, at radius of gyration) of synchronous machine

s = slip, or decrease of velocity, as fraction of v_0, where s is a (periodic) function of time; hence:

$v = v_0\,(1-s)$ = actual velocity, at time t.

During the time element dt, the position of the synchronous motor armature regarding the impressed e.m.f. e_0, and thereby the phase angle $\beta+\delta$ of e, changes by:

$$d\,\delta = 2\,\pi\,N\,s\,dt$$

$$= s\,d\,\varphi \qquad (15)$$

where: $\varphi = 2\,\pi\,N\,t$

and: N = frequency of impressed e.m.f. e_0

Let:

m = mass of revolving machine elements, and

$M_0 = \frac{1}{2}\,m\,v_0^2$ = mean mechanical momentum, reduced to joules or watt-seconds, then the momentum at time t and velocity $v = v_0\,(1-s)$ is:

$$M = \tfrac{1}{2}\,m\,v_0^2\,(1-s)^2$$

and the change of momentum during the time element dt is:

$$\frac{d\,M}{dt} = -\,m\,v_0^2\,(1-s)\,\frac{d\,s}{dt}$$

hence, for small values of s:

$$\frac{d\,M}{dt} = -\,m\,v_0^2 \frac{ds}{d\,\varphi}\,\frac{d\,\varphi}{dt}$$

$$= -\,2\,M_0 \frac{d\,s}{d\,\varphi}\,\frac{d\,\varphi}{dt} \tag{16}$$

since:

$$\frac{d\varphi}{dt} = 2\,\pi\,N, \text{ and from (15):}$$

$$s = \frac{d\,\delta}{d\,\varphi}$$

$$\frac{d\,s}{d\,\varphi} = \frac{d^2\delta}{d\varphi^2}$$

it is:

$$\frac{d\,M}{dt} = -\,4\,\pi\,N\,M_0 \frac{d^2\,\delta}{d\,\varphi^2} \tag{17}$$

Since, as discussed, the change of momentum equals the difference between produced and consumed power, the excess of power being converted into momentum, it is:

$$P - P_0 = \frac{d\,M}{dt} \tag{18}$$

and, substituting (14) and (17):

$$\frac{e\,e_0}{z} \sin\frac{\delta}{2} \sin\left(a - \beta - \frac{\delta}{2}\right) + 2\,\pi\,N\,M_0 \frac{d^2\,\delta}{d\,\varphi^2} = 0 \tag{19}$$

Assuming δ as a small angle, that is, considering only small oscillations, it is:

$$\sin\frac{\delta}{2} = \frac{\delta}{2}$$

$$\sin\left[a - \beta - \frac{2}{\delta}\right] = \sin\,(a - \beta)$$

hence, substituted in (18):

$$\frac{e\,e_0}{z}\,\delta \sin\,(a - \beta) + 4\,\pi\,N\,M_0 \frac{d^2\,\delta}{d\,\varphi^2} = 0 \tag{20}$$

and, substituting:

$$a = \frac{e\,e_0 \sin\,(a - \beta)}{4\,\pi\,N\,z\,M_0} \tag{21}$$

it is:

$$a\,\delta + \frac{d^2\,\delta}{d\,\varphi^2} = 0 \tag{22}$$

This differential equation is integrated by:

$$\delta = A\,\varepsilon^{C\varphi} \tag{23}$$

which, substituted in (22) gives:

$$a\,A\,\varepsilon^{C\varphi} + A\,C^2\varepsilon^{C\varphi} = 0$$

$$a+C^2=0$$

$$C=\pm\sqrt{-a} \qquad (24)$$

(1) If $a<0$, it is:

$$\delta = A_1\,\varepsilon^{+m\phi} + A_2\,\varepsilon^{-m\phi}$$

where

$$m=\sqrt{-a}=\sqrt{\frac{e\,e_0\sin(\beta-a)}{4\,\pi\,N\,z\,M_0}}$$

Since in this case, $\varepsilon^{+m\phi}$ is continually increasing, the synchronous motor is unstable. That is, without oscillation it drops out of step, if $\beta>a$

(2) If $a>0$, it is, denoting:

$$n=+\sqrt{a}=+\sqrt{\frac{e\,e_0\sin(a-\beta)}{4\,\pi\,N\,z\,M_0}}$$

$$\delta = A_1\,\varepsilon^{+jn\phi} + A_2\,\varepsilon^{-jn\phi}$$

or, substituting for $\varepsilon^{+jn\phi}$ and $\varepsilon^{+jn\phi}$ the trigonometric functions:

$$\delta = (A_1+A_2)\cos n\,\varphi + j\,(A_1-A_2)\sin n\,\varphi$$

or: $$\delta = B\cos(n\,\varphi+\gamma) \qquad (25)$$

That is, the synchronous motor is in stable equilibrium, when oscillating with a constant amplitude B, depending upon the initial conditions of oscillation, and a period, which for small oscillations gives the frequency of oscillation:

$$N_0 = n\,N$$

$$=\sqrt{\frac{N\,e\,e_0\sin(a-\beta)}{4\,\pi\,z\,M_0}} \qquad (26)$$

In the instance given in Part I it is:

$e_0 = 2{,}200$ volts. $Z = 1-4\,j$ ohms, or: $z = 4.12$; $a = 76°$

Let the machine, a 16-polar 60-cycle 400 k.w. revolving field synchronous motor, have the radius of gyration of 20″, a weight of the revolving part of 6,000 lbs.

The momentum then is: $M_0 = 850.000$ joules.

Deriving the angles β, corresponding to given values of output P and excitation e, from the polar diagram, or from the symbolic representation, and substituting in (26), gives the frequency of oscillation:

$P = 0$:

$e = 1600$ volts	$\beta = -2^\circ$	$N_0 = 2.17$ cycles, or	130	periods	per	min.
2180 "	$+3^\circ$	2.50 "	150	"	"	"
2800 "	$+5^\circ$	2.85 "	169	"	"	"

$P = 400$ k.w.

$e = 1600$ volts	$\beta = 33^\circ$	$N_0 = 1.90$ cycles, or	114	periods	per	min.
2180 "	21°	2.31 "	139	"	"	"
2800 "	22°	2.61 "	154	"	"	"

As seen, the frequency of oscillation does not vary much with the load and with the excitation. It slightly decreases with increase of load, and it increases with increase of excitation.

In this instance, only the momentum of the motor has been considered, as would be the case for instance in a synchronous converter.

In a direct connected motor-generator set, assuming the momentum of the direct current generator armature equal to 60% of the momentum of the synchronous motor, the total momentum is: $M_0 = 1,360,000$ joules, hence, at no load:

$$P = 0$$

$e = 1,600$ volts: $N_0 =$	1.72 cycles, or	103	periods	per	min.
	1.98 "	119	"	"	"
	1.23 "	134	"	"	"

III.

In the preceding discussion of the surging of synchronous machines, the assumption has been made, that the mechanical power consumed by the load is constant, and that no damping or anti-surging devices were used.

The mechanical power consumed by the load varies, however, more or less with the speed, approximately proportional to the speed if the motor directly drives mechanical apparatus, as pumps, etc., and at a higher power of the speed if driving direct current generators, or as synchronous converter, especially when in parallel, with other direct current generators. Assuming, then, in the general case the mechanical power consumed by the load to vary, within the narrow range of speed variation considered during the oscillation, as the p th power of the speed, in the preceding equation instead of P_0 is to be substituted: $P_0 (1-s)^p = P_0 (1 - p s)$.

If anti-surging devices are used, and even without these in machines in which eddy currents can be induced by the oscillation of slip, in solid field poles, etc., a torque is produced more or less proportional to the deviation of speed from synchronism. This power assumes the form $P_1 = c^2 s$, where c^2 is a function of the conductivity of the eddy current circuit and the intensity of the magnetic field of the machine. c^2 is the power which would be required to drive the magnetic field of the motor through the circuits of the anti-surging device at full frequency, if the same relative proportions could be retained at full frequency as at the frequency of slip s. That is, P_1 is the power produced by the motor as induction machine at slip s. Instead of P, the power generated by the motor, has to be substituted then in the preceding equations the value $P + P_1$.

The equation (18) then assumes the form:

$$P + P_1 - P_0 (1 - p s) = \frac{d M}{dt} .$$

or:

$$(P - P_0) + (P_1 + p P_0 s) = \frac{d M}{dt} \tag{27}$$

or, substituting (17) and (14)

$$\frac{2 e e_0}{z} \sin \frac{\delta}{2} \sin [a - \beta \frac{\delta}{2}] + (c^2 + p P_0) \frac{d \delta}{d \varphi} +$$

$$4 \pi N M_0 \frac{d^2 \delta}{d \varphi^2} = 0 \tag{28}$$

and, for small values of δ:

$$a \delta + 2 b \frac{d \delta}{d \varphi} + \frac{d^2 \delta}{d \varphi^2} = 0 \tag{29}$$

$$a = \frac{e e_0 \sin a - \beta}{4 \pi N z M_0}$$

$$b = \frac{c^2 + p P_0}{8 \pi N M_0} \tag{30}$$

Of these two terms b represents the consumption, a the oscillation of energy by the pulsation of phase angle β. b and a thus have a similar relation as resistance and reactance in alternating current circuits, or in the discharge of condensers. a is the same term as in part II.

Differential equation (29) is integrated by:
which, substituted in (29) gives:

$$\delta = A\, \varepsilon^{C\phi} \tag{31}$$

$$a\, A\, \varepsilon^{C\phi} + 2\, b\, C\, A\, \varepsilon^{C\phi} + C^2 A\, \varepsilon^{C\phi} = 0$$

$$a + 2\, b\, C + C^2 = 0$$

which equation has the two roots:

$$C_1 = -b + \sqrt{b^2 - a}$$
$$C_2 = -b - \sqrt{b^2 - a} \tag{32}$$

(1) If: $a < 0$, or negative, that is, $\beta < \alpha$, C_1 is positive and C_2 negative, and the term with C_1 is continuously increasing, that is, the synchronous motor is unstable, and, without oscillation, drifts out of step.

(2) If: $0 < a < b^2$, or a positive, and b^2 larger than a (that is, the energy consuming term very large), C^1 and C^2 are both negative, and, by substituting: $+\sqrt{b^2 - a} = f$, it is:

$$C_1 = -(b - f), \qquad C_2 = -(b + f)$$

hence:

$$\delta = A_1\, \varepsilon^{-(b-f)\,\phi} + A_2\, \varepsilon^{-(b+f)\,\phi} \tag{33}$$

That is, the motor steadies down to its mean position logarithmically, or without any oscillation.

$$b^2 < a$$

or:

$$\frac{(c^2 + p\, P_0)^2}{16\, \pi\, N\, M_0} < e\, e_0 \sin \frac{\alpha - \beta}{z} \tag{34}$$

is the condition under which no oscillation can occur.

As seen, the left side of (34) contains only mechanical, the right side only electrical terms.

(3) $a > b^2$.

In this case, $\sqrt{b^2 - a}$ is imaginary, and, substituting:

$$g = \sqrt{a - b^2}$$

it is:

$$C_1 = -b + j\, g$$
$$C_2 = -b - j\, g$$

hence:

$$\delta = \varepsilon^{-b\phi}\left[A_1\, \varepsilon^{+jg\phi} + A_2\, \varepsilon^{-jg\phi}\right]$$

and, substituting the trigonometric for the exponential functions, gives ultimately:

$$\delta = B \varepsilon^{-b\phi} \cos(g\varphi + \delta) \quad (35)$$

That is, the motor steadies down with an oscillation of period:

$$N_0 = g N$$

$$= \sqrt{\frac{N e e_0 \sin(\alpha - \beta)}{4 \pi z M_0} - \frac{(c^2 + p P_0)^2}{64 \pi^2 M_0^2}} \quad (36)$$

and decrement or attenuation constant.

$$b = \frac{c^2 + p P_0}{8 \pi N M_0}$$

IV.

It follows, however, that under the conditions considered, a cumulative surging, or an oscillation with continuously increasing amplitude, cannot occur, but that a synchronous motor, when displaced in phase from its mean position, returns thereto either aperiodically, if $b^2 > a$, or with an oscillation of vanishing amplitude, if $b^2 < a$. At the worst, it may oscillate with constant amplitude, if $b = 0$.

Cumulative surging can, therefore, occur only if in the differential equation,

$$a \delta + 2 b \frac{d \delta}{d \varphi} + \frac{d^2 \delta}{d \varphi^2} = 0 \quad (29)$$

the coefficient b is negative.

Since c^2, representing the induction motor torque of the damping device, etc., is positive, and $p P_0$ is also positive (p being the exponent of power variation with speed), this presupposes the existence of a third and negative term $\frac{-h^2}{8\pi N M_0}$ in b:

$$b = \frac{c^2 + p P_0 - h^2}{8 \pi N M_0} \quad (39)$$

This negative term represents a power:

$$P_2 = - h^2 s \quad (38)$$

that is, a retarding torque during slow speed, or increasing β, and accelerating torque during high speed, or decreasing β.

The source of this torque may be found external to the motor, or internal, in its magnetic circuit.

External sources of negative P_2 may be, for instance, the magnetic field of a self-exciting direct current generator, driven by the synchronous motor. With decrease of speed, this field decreases, due to the decrease of generated voltage, and increases with increase of speed. This change of field strength, however, lags behind the exciting voltage and thus speed, that is, during decrease of speed the output is greater than during increase of speed. If this direct current generator is the exciter of the synchronous motor, the effect may be intensified.

The change of power input into the synchronous motor, with change of speed, may cause the governor to act on the prime mover driving the generator, which supplies power to the motor, and the lag of the governor behind the change of output gives a pulsation of the generator frequency, of e_0, which acts like a negative power P_2. The pulsation of impressed voltage, caused by the pulsation of β, may give rise to a negative P_2 also.

An internal cause of a negative term P_2 is found in the lag of the synchronous motor field behind the resultant m.m.f. In the preceding discussion, e is the " nominal induced e.m.f." of the synchronous machine, corresponding to the field excitation. The actual magnetic flux of the machine, however, does not correspond to e, and thus to the field excitation, but corresponds to the resultant m.m.f. of field excitation and armature reaction, which latter varies in intensity and in phase during the oscillation of β. Hence, while e is constant, the magnetic flux is not constant, but pulsates with the oscillations of the machine. This pulsation of the magnetic flux lags behind the pulsation of m.m.f., and thereby gives rise to a term in b equation (37). If P_0, β, e, e_0, Z are such that a retardation of the motor increases the magnetizing, or decreases the demagnetizing force of the armature reaction, a negative term P_2 appears, otherwise a positive term.

P_2 in this case is the energy consumed by the magnetic cycle of the machine at full frequency, assuming the cycle at full frequency as the same as at frequency of slip s.

Or inversely, e may be said to pulsate, due to the pulsation of armature reaction, with the same frequency as β, but with a phase, which may either be lagging or leading. Lagging of the pulsation of e causes a negative, leading a positive P_2.

P_2, therefore, represents the power due to the pulsation of e caused by the pulsation of the armature reaction.

Any appliance increasing the area of the magnetic cycle of pulsation, as short-circuits around the field poles, therefore, increases the steadiness of a steady, and increases the unsteadiness of an unsteady synchronous motor.

In self-exciting synchronous converters, the pulsation of e is intensified by the pulsation of direct current voltage caused thereby, and hence of excitation.

Introducing now the term $P_2 = - h^2 s$ into the differential equations of Part III., gives the additional cases:

$b < 0$, or negative, that is:

$$\frac{c^2 + p P_0 - h^2}{8 \pi N M_0} < 0 \qquad (39)$$

Hence, denoting:

$$b_1 = - b = \frac{h^2 - c^2 - p P_0}{8 \pi N M_0}$$

gives:

(4) if: $b_1^2 > a$: $f = + \sqrt{b_1^2 - a}$

$$\delta = A_1 \varepsilon^{+(b_1 + f)\phi} + A_2 \varepsilon^{+(b_1 - f)\phi} \qquad (40)$$

That is, without oscillation, the motor drifts out of step, in unstable equilibrium.

(5) if: $a > b^2$: $g = \sqrt{a - b_1^2}$

$$\delta = B \varepsilon^{+ b_1 \phi} \cos (g \varphi + \delta) \qquad (41)$$

That is, the motor oscillates, with constantly increasing amplitude, until it drops out of step. This is the typical case of cumulative surging by electro-mechanical resonance.

The problem of surging of synchronous machines, and its elimination, thus resolves into the investigation of the coefficient:

$$b = \frac{c^2 + p P_0 - h^2}{8 \pi N M}$$

while the frequency of surging, where such exists, is given by:

$$N_0 \sqrt{\frac{(N e e_0 \sin (a - \beta)}{4 \pi z_0 M_0} - \frac{(c^2 + p P_0 - h^2)^2}{64 \pi^2 M_0^2}}$$

Case (4), steady drifting out of step, has only rarely been observed.

The avoidance of surging thus requires:

(1) An elimination of the term h^2, or reduction as far as possible.

(2) A sufficiently large term c^2 or

(3) A sufficiently large term $p\,P_0$.

(1) refers to the design of the synchronous machine and the system on which it operates. (2) leads to the use of electromagnetic anti-surging devices, as an induction motor winding in the field poles, short-circuits between the poles, or around the poles, and (3) leads to flexible connection to a load or a momentum, as flexible connection with a flywheel, or belt drive of the load.

The conditions of steadiness are:

$$\beta < \alpha$$

$$c^2 + p\,P_0 - h^2 > 0$$

and if:

$$\frac{(c^2 + p\,P_0 - h^2)^2}{(16\,\pi\,N\,M_0)} > \frac{e\,e_0 \sin(\alpha - \beta)}{z}$$

no oscillation at all occurs, otherwise an oscillation with decreasing amplitude.

NINETEENTH ANNUAL CONVENTION.

OPENING SESSION.

Discussion at Great Barrington, June 18th. Papers by F. G. Baum, M. Leblanc, H. W. Buck and Charles P. Steinmetz.

PRESIDENT STEINMETZ:—Gentlemen, Members of the INSTITUTE and Guests: I now call to order the Nineteenth Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Following our previous practice, we hold the Annual Convention outside of the place of our regular monthly meeting, this time in a very pleasant country village, and I hope you will enjoy the convention very much, especially as we have been so very well and cordially received, in somewhat striking contrast to some experiences in former times.

[After presentation of papers by the authors named above, the discussion proceeded as follows:]

DR. F. A. C. PERRINE:—I have some notes here for closing the discussion on Mr. Baum's paper which I think we might as well read. Mr. Baum wrote me a letter that I thought might possibly be required in answering some questions, but as I did not hear the questions, I will read the letter anyway.

"STOCKTON, CAL., Jan. 1, 1901.

DR. F. A. C. PERRINE.

DEAR SIR:—As I telegraphed you on December 28, 1900, I made a practical test of the compensator at Stockton. I was able to make arrangements with Mr. Adams to start 15, 20, 25 and 75 h.p. motors on the G. E. 100 k.w. synchronous motor, which is now being run as a generator. This generator is a bad regulator (having been built for motor work), the reactive pressure being about 20 per cent. on full load current, and the starting of the 75 h.p. Westinghouse type C, (Farmer's Union) motor is as severe a test as you will ever get in practice.

I thought the conditions here for giving the compensator a severe test were better than at Maryville, and therefore did not go up there. I am convinced that I could start this 75 h.p. motor on a 50 k.w. generator, and not cause more than a momentary dip of the lights.

The compensator was driven in synchronism by a gearing on the shaft. This gearing is satisfactory, but usually when several alternators are to be compensated, the compensator would be driven by a small synchronous motor. A synchronous motor for the purpose can be made by winding a ¼ h.p. motor frame. Since a 1¼ h.p. motor will make a compensator large enough to take care of a 2,000 k.w. generator or station, you need not go to any expense in getting out new patterns, etc., for the compensator. For smaller generators 50 to 200 or 300 k.w., a smaller machine than the ¼ h.p. motor could be used for the compensator.

Starting test of 20 h.p. G. E. (Hyatt) motor, on 100 k.w. G. E.

generator. (Speed change in engine varies the voltage from 114 to 118; railroad on same engine.)

	CONDITIONS BEFORE START	START	MOTOR RUNNING.
Alternating Amperes,	6.25	15	9
" Voltage,	116.	114	116
Exciter Amperes,	9.25	10	9.5

No change in rheostat necessary. Voltage dips to 114 but returns to 116 in less than two seconds. This dip is on account of the lag in magnetism spoken of.

Without compensator, when this motor is started, the voltage drops 10 to 20 volts, and must be brought back by turning rheostat handle. Station must be notified when motor is thrown on or off. No notice is necessary when compensator is in.

Start 75 h.p. Westinghouse type C (Farmer's Union) motor on 100 k.w. G. E, generator.

	BEFORE START.	START.	MOTOR RUNNING.
Alternating Amperes	10	Over 50 amperes.	15
" Voltage,	116	95	116
Exciter Amperes,	9.75	12.75	11.5
		Ammeter needle off scale.	

No change in rheostat. Voltage dips to 95, but comes back to 116 in about two seconds. Note that the exciting current immediately jumps from 9.75 to 12.75, an increase of 32 per cent., and then gradually drops as the speed of the motor increases, to 11.5 amperes, where it remains. Rheostat was not touched. When motor is cut off, alternator voltage remains at 116.

Without compensator, the voltage drops when this motor is started to about 85, and remains down about 100 until brought up by station attendant. Station must be notified when the motor is thrown on or off. No notice is necessary when compensator is used.

Yours truly,

(Signed) F. G. BAUM.

PROF. C. A. ADAMS:—I should like to ask Dr. Perrine about the compensator.

DR. PERRINE:—The sparking is one of the things that Mr. Baum attempts to get rid of by the arrangement shown in Fig. 6, where he obtains a very small current from the compensator largely to do away with sparking, and uses that to excite an auxiliary exciter, which in turn excites the extra winding of the excited field. When he attempts to use a compensator directly, he is apt to get considerable sparking, but he gets rid of the sparking by making the current very small—a current of the maximum of an ampere is sufficient to do all the work when he uses this auxiliary exciter.

PROF. ADAMS:—My inquiry was if in this latter case he gets rid of the sparking.

DR. PERRINE:—He does not get rid of it, but he uses such a small current it does no harm.

PROF. ADAMS:—How would you get rid of sparking in using 1,500 k.w. instead of 200 k.w.?

DR. PERRINE:—The compensator in any case is a small outfit; he uses that to act on a secondary exciter, and he always keeps his current in the compensator small, even when compensating from a large generator.

MR. ADAMS:—It would be possible, then, to use a small compensator for the exciter, regardless of the size of the generator?

DR. PERRINE:—Yes, provided the winding of the secondary exciter is correct; that is, he need not change the current in the compensator at all.

Concerning Mr. Buck's paper there are a few things of which I would like information from Mr. Buck. At the time the original plant was built, we heard a great deal of the manner of carrying the heavy shaft and I would like to know whether there has been any change in the design of the thrust bearings along the shaft which carry that shaft. Also whether anything has been done to obviate the extreme wabbling of the 30-inch shaft. I was in the wheel-pit of the old power-house a short time ago with some Western engineers, and we all noticed that the 30-inch shaft seemed to be running out an inch or two, and the question was raised, even though it may be considered trivial, whether it really was not straining the material, and bringing about the effect that we commonly know as crystallization, which is not crystallization, but simply the exceeding of the elastic limit to a very small extent continuously, which ultimately overcomes the elasticity of the entire material, and it appeared to be a good thing to get rid of.

On the seventh page of the paper is given the guaranteed and test efficiencies of the old machines, and nothing is said of the efficiencies of the new machines. I do not presume from those efficiencies they can be very much greater, and may be less, but it would be interesting if we knew approximately what those efficiencies are.

I agree with Mr. Buck entirely in the question of the arrangement of his switchboard, namely, that the bench system in combination with the instruments on panels is bad. The bench system to my mind, is only practical where the station is so small that the instruments can be arranged so close together that lines drawn from the bench will come directly on the switchboard panels. What I mean by that is this: if we have a switchboard with instruments on, and divided into panels, and an operating table of smaller dimensions, then the benchboard is permissible if the switchboard is short enough to be within the eye of the attendant, and his small switches located with lines drawn showing what they represent on the instrument board; then when a man puts his hand on any particular switch, by following his lines he goes directly to the instruments he is operating. But I agree with Mr. Buck entirely, it is poor practice to have an operating table at one point and the instruments that are operated from that table 20 or 30 feet on either side. Obviously, a man cannot tell what he is doing; and furthermore, the advantage of having all of the switches at any station under a man's immediate hand is more or less fictitious. It is rare that a man at any one time will want to handle more than two machines, and they are generally adjacent machines; the cases are 99 out of 100 where an operator has not before him all the switches he needs to have. In this Niagara station I first saw the method of putting all the recording apparatus in the superintendent's office, and it seemed to me that is really where they belong. There is only one thing to my mind worse than putting wattmeters on the switchboard, and that is lightning arresters. The operator at the station should have before him such instruments and such apparatus as he must necessarily use in handling the station, and only such apparatus. If the station operator has before him instruments that he does not need to use in operating the station, and whose indications he does not need to consider, he gradually loses his respect for all indication of instruments; and I believe that there should be before the station operator only the things he has to pay attention to and use. This idea of putting on the switchboard all kinds of phase indicators, and frequency indicators and indicators of everything under the sun, is to my mind an absolutely vicious practice. The station attendant ought to have before him such apparatus that every movement of a needle tells him something, and he should not have wattmeters, for example, any more on his switchboard than he should have lightning arresters; and with the three-phase generator he does not need three voltmeters and three ammeters; and to put apparatus there that the station attendant positively cannot control, I think is confusing to his mind. This Niagara plant is the first one where this principle was put in practice, and I am very glad to see it carried out in this latest development. The change from an external revolving field to the internal revolving field seems, in our ideas of the Niagara plant, very radical; but the speeds of those generators are not greater than the speeds that are being used in other revolving field plants and the construction I imagine is very much similar; and it seems to me the change is a distinct practical improvement in the construction.

Mr. Buck:—Replying to Dr. Perrine, the average weight of the rotating parts of the machinery in power-house No. 2 will be carried as in the old plant, upon a hydraulic step at the bottom of the shaft, and the variations in downward thrust due to variations in head of water, will be taken care of by an oil thrust bearing near the top of the shaft, which is operated by oil under pressure of several hundred pounds per square inch. The friction of this oil thrust bearing is so slight that when the machine is standing still a man can turn it around by hand.

In regard to the apparent eccentricity of the shaft, I think that it is due to the shaft being hollow, and made of lapped boiler iron. Every time a lap goes around it looks as if the shaft were out of true, but the shaft as a whole is centered so that there is no wabble on the bearings. The test efficiency of the internal field generators was not given for the reason that these machines have not yet been tested. The guaranteed efficiency is 2/10 of 1 per cent. lower at full load, than that of the external field generators.

In the old power-house the indicating and recording wattmeters are both placed in the office of the superintendent. In the new plant the indicating meters will be transferred to the switchboard and the recording wattmeters only retained in the office of the superintendent.

MR. A. V. GARRATT:—The drawing is on so small a scale that it is difficult to tell what style of gate the turbine has. It will be interesting if Mr. Buck will advise us as to what type of turbine is being used, and also where turbines of this particular type have been installed, if at all, in this country, and what success has been obtained with them in regard to speed regulation.

MR. BUCK:—I do not think that any turbines of this exact design have yet been installed in this country, but there are a number installed in Switzerland and other European countries, and I understand that the results obtained have been very satisfactory. In this design, the water coming down the penstock enters the wheel case, which is spherical in form, and from there discharges inward through a double set of buckets which are controlled by ring gates from above. From the inside of the rotating part, the water is drawn out through double draft tubes as shown.

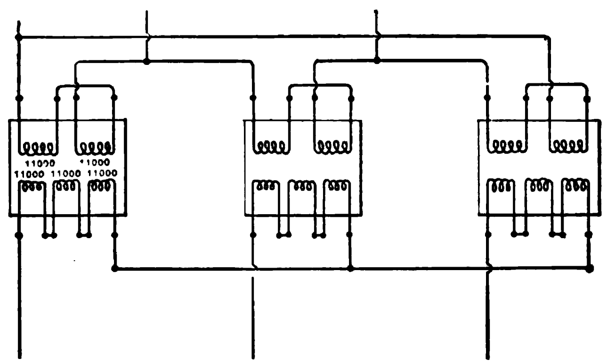
MR. P. H. THOMAS:—There is a little more, it seems to me, that should be said on the uses of benchboards in these large systems. Of course it is very important to have the attendant see the instruments on the panel on which he is going to throw switches, but it is also important that he should know as well the actual connections on the rest of the system. In many cases I should think the latter would be more important than seeing the indications of the instruments. A complete knowledge of the connections of the system is very easily obtained by the benchboard system. Undoubtedly, however, some plants can be more satisfactorily handled with the feeder system than with a benchboard.

Mr. Buck, do you expect to pay duty on your power when you are transferring it from Canada to the United States?

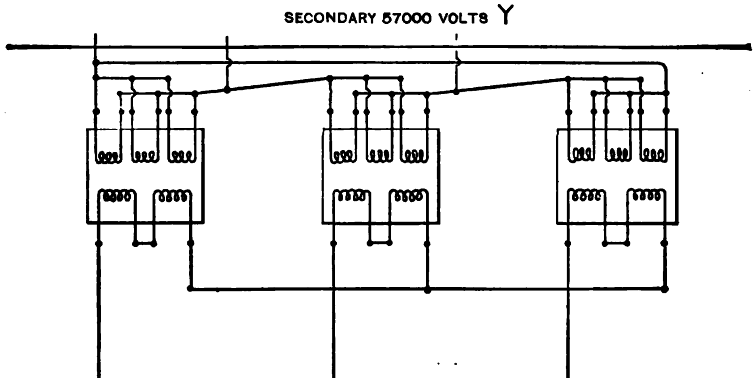
MR. BUCK:—In regard to Mr. Thomas's first point, I quite agree with him that there might be some special case where benchboard control would be of advantage, but where you have a large number of generator panels and feeder panels it is impossible to get instruments arranged in such a way that there would be no confusion.

In regard to the duty on power, that matter was settled, I believe, by Congress and also by the Canadian Parliament, and a reciprocal arrangement arrived at.

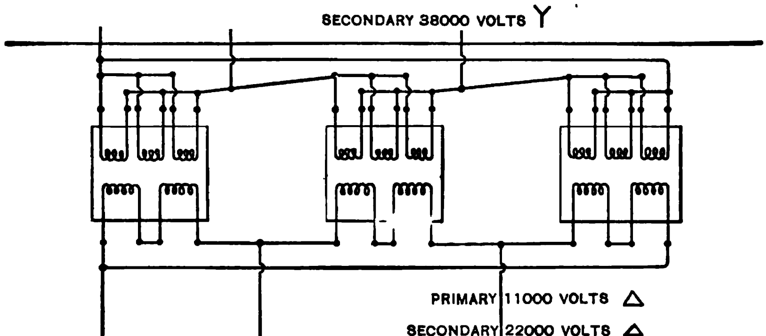
PRESIDENT STEINMETZ:—In Mr. Buck's paper the statement



PRIMARY 11000 VOLTS Δ
SECONDARY 57000 VOLTS Y



PRIMARY 11000 VOLTS Δ
SECONDARY 38000 VOLTS Y



PRIMARY 11000 VOLTS Δ
SECONDARY 22000 VOLTS Δ

is made that the output of the Canada plant is intended for long-distance transmission to Toronto, I believe. We would all be interested to hear somewhat more of what is intended to be done there and what work is in progress regarding the transmission. The distance is rather long, pretty well up to 100 miles, and the climate is not so lovely as in southern California, and it would be quite interesting to hear what Niagara expects to do.

MR. BUCK:—Up to the present time nothing very definite has been done upon the Toronto transmission line, but negotiations are now pending and it is likely that construction will start before long. The line is to be arranged for operation at either 40,000 or 60,000 volts. The arrangement of step-up transformers selected for this transmission may be of interest to the INSTITUTE, and I will illustrate the construction on the blackboard. [See Fig. 1]. The transformers are designed with five similar coils, two of which constitute one winding and three the other winding, either of which can be used interchangeably as primary and secondary. By the various combination of coils as shown in the sketch, any of the voltages shown can be used with the full copper efficiency of the transformers.

PRESIDENT STEINMETZ:—If there is no further discussion today, then a motion to adjourn will be in order. Before we adjourn I desire to say this: We have postponed two papers which we had scheduled for this forenoon's meeting. We have a very large programme for to-morrow and the following day, therefore it will be absolutely necessary to start the meeting punctually at 9 o'clock.

Announcement regarding social features in connection with the Convention were then made by Mr. Stanley, after which the session adjourned.

In the afternoon the members with their ladies were entertained at a Lawn Tea, under the auspices of the Thursday Morning Club, at Brookside, the residence of Mr. and Mrs. William Stanley.

In the evening a Lantern Exhibition arranged by the Committee on Papers was given by the INSTITUTE at the Town Hall. Groups of slides upon various subjects were shown and described by the members named, who were introduced by the Secretary: Messrs. T. Commerford Martin, W. B. Spellmire, F. A. C. Perrine and W. J. Jenks.

A paper presented at the 19th Annnual Convention of the American Institute of Electrical Engineers Great Barrington, Mass., June 19th, 1902.

A STUDY OF THE HEATING OF RAILWAY MOTORS.

BY A. H. ARMSTRONG.

The electric traction problem presents many new features for investigation which are not met with in steam railroading, and upon which little accurate data has been published. This is especially true of that class of service calling for maximum speeds greater than 35 or 40 m.p.h., where stops are infrequent and cars are run singly or in trains of two cars or more. It is the purpose of this paper to enter into a discussion of some of the variables met with and their influence upon the motive power and station output for the higher as well as the lower speed schedules.

The electrical engineer has to take care of two factors with which the steam engineer is unacquainted, keeping the temperature of the motive power within reasonable limits, and also the operation of single cars at maximum speeds of 60 to 70 m.p.h. That wind friction is a considerable factor with trains operating at high speeds has been abundantly proved by many tests, but these tests are worthless when used to determine the power required to propel a single car at the same high speeds. As the electric motor has invaded the high-speed interurban field and has done so successfully because of the frequency of service furnished with single-car trains, it becomes pertinent to inquire into the size of the motive power necessary to prevent overheating and also the amount of power needed with the high speed schedules and frequent stops made.

Regarding the tractive effort required to propel trains of one or two cars at speeds of 60 m.p.h. or more, there is almost a complete lack of experimental data. Formulæ based upon tests of steam trains made up of a number of heavy coaches cannot be applied with any accuracy to the operation of single car units. A series of tests made by the General Electric Company on the Buffalo and Lockport tracks, with trains of different sizes, provides almost the only data upon which to base such calculations. These tests were carried up to speeds approaching 60 m.p.h. with ordinary steam railway coaches, hauled by a 38-

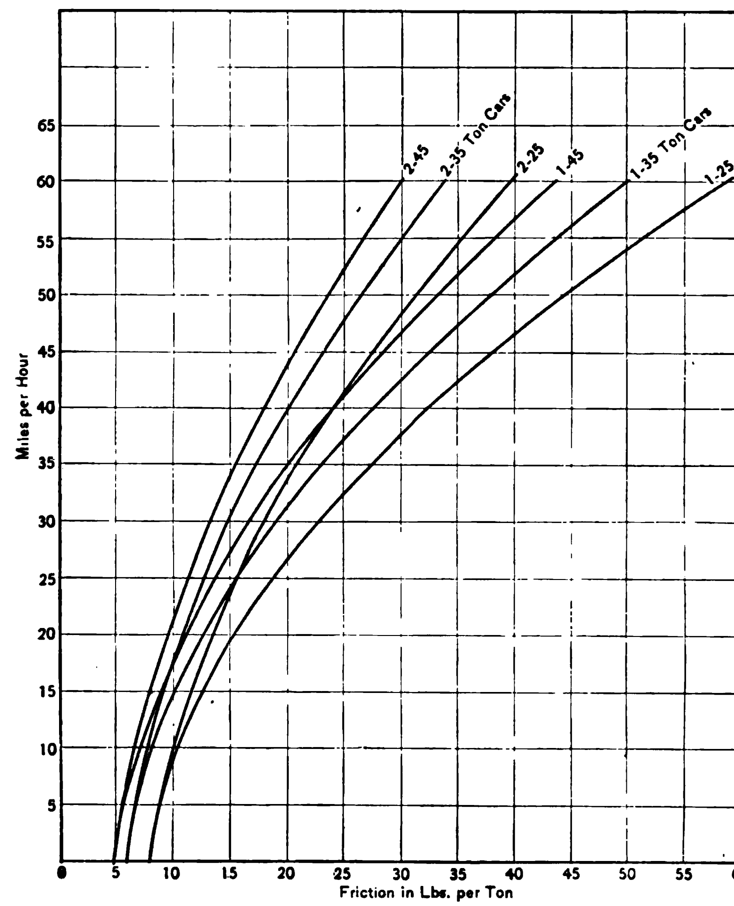


FIG. 1.

ton electric locomotive. The cars were not vestibuled and the conditions were not, therefore, such as to give results directly applicable to the operation of single suburban cars of the vestibule type. For want of more accurate data, these tests will be used as the basis of the following calculations, and, as the curves deduced are used for comparison only, it makes little difference if the friction values are not absolutely correct These train friction tests were published in the May issue of the *Street Railway Journal*, by Mr. W. J. Davis, Jr., and for convenience of reference some of the curves are here reproduced as Fig. 1.

The tendency of the electric roads has been toward heavier cars, especially on the higher speed lines, where the car weights run from 25 to 45 tons,including equipment and seated passenger load. Suppose we equip cars weighing 25, 35 and 45 tons with the same four-motor equipment, geared for 60 m.p.h. with the 35-ton car, there would then result speed time-curves as in Fig. 2, the speed curve of the 45-ton car falling below and that

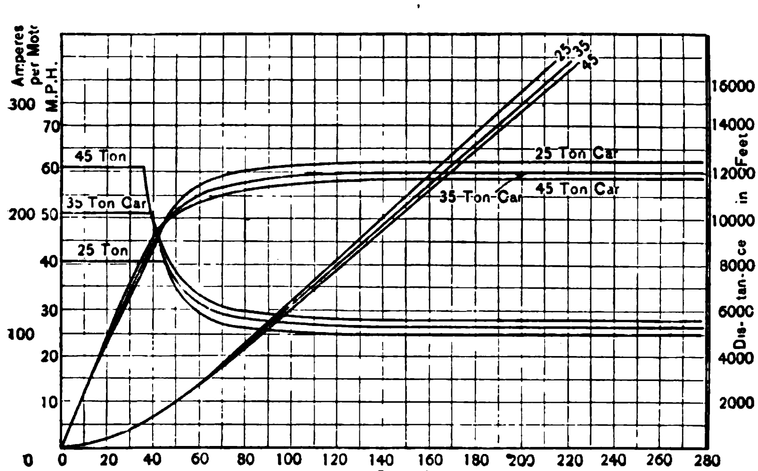


FIG. 2.

of the 25-ton car rising above that of the 35-ton car for the same gear ratio. A tractive effort of 120 lbs. per ton gross has been taken with all three equipments, as representing average conditions for this class of work, giving a net acceleration of about 1.06 m.p.h per second, after deducting friction loss and the power required to accelerate the revolving parts. Any other rate of acceleration could have been taken with little or no effect upon the heating of the motive power or its energy consumption, as will be shown later, the larger part of the energy input being used up in overcoming air resistance at this high speed.

Speed and amperes input are plotted as ordinates with time as abscissa and power may be shut off at any time, the car allowed to coast and brought to rest by brakes, making the enclosed area of the speed-time curve proportional to the distance covered, and the area of the ampere-time curve equal the ampere hours input. For the sake of simplicity it has been assumed that the friction will be the same at the same speeds during acceleration and coasting; that is, that the energy given up by the rotating parts during coasting will equal the gear and friction loss of the motors running light, an assumption which is approximately correct. The coasting curve will, therefore, follow the shape of the friction curves in Fig. 1, will be curved and show a greater retardation at high than at low speeds.

While power is applied, the motive power has internal losses, varying not only in intensity but in their distribution. At zero

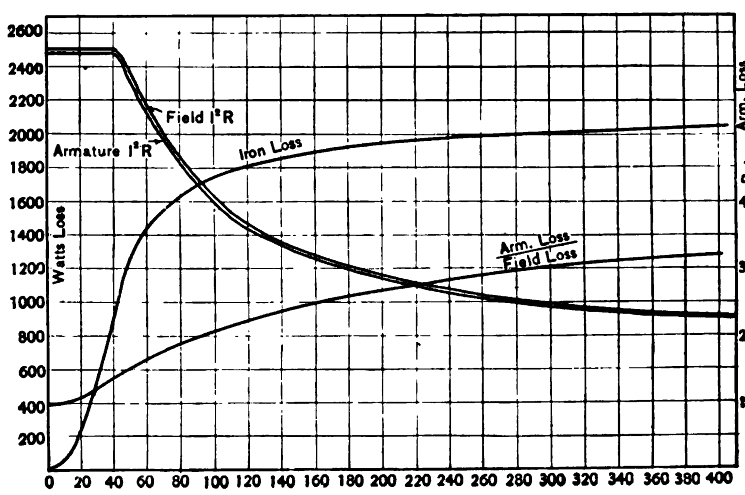


FIG. 3.

speed, the losses are all in the copper of field and armature, being divided according to their relative resistances, but as the armature speed increases there is an iron loss distributed between the iron of armature and pole-face and tips, depending upon the design of the motor. This iron loss starts from zero at standstill and increases to a maximum at the moment of cutting out starting resistances, after which it falls off somewhat, but this again is a matter of motor design. As these various losses are the cause of our motive power heating, it is necessary to trace their influence upon the individual parts of the motor under study.

As the heating of a motor is the result of the average losses within it, the average losses and their distribution up to any moment of shutting off power must be determined. Such losses are shown in Fig. 3 for our 35-ton car equipment, speed and ampere curves of which are shown in Fig. 2. The motor losses for 25 and 45-ton cars have been left off to avoid confusion, but from the shape of the ampere-time curve in Fig. 2, it is evident that the curves will vary greatly from those shown only during the fractional speed or acceleration period, these differences being virtually wiped out with a considerable amount of running upon the motor curve. Thus, while there is a total average copper loss of 5,000 watts during acceleration upon resistance, the copper-loss curve becomes flat in about 400 seconds at the value of 1,800 watts in the copper, with the motor constants chosen. As an equipment geared for a maximum speed of 60 m.p.h. would hardly be used for an average run of less than 15,000 feet, requiring power on for fully 160 seconds for its accomplishment, it will be seen that the acceleration losses play a comparatively unimportant part in very high speed work, so far as the motor heating is concerned. That this is not true of low speed work will be discussed later.

The iron loss has been assumed to be dissipated entirely from the armature in arriving at the " ratio of losses " in Fig. 3. This is not strictly true, but the true subdivision of losses, whatever it may be, will be practically the same with the same ratio of losses, and hence any values of motor heating deduced from curves similar to Fig. 3 must be consistent. For example, if we know the degrees rise per watt loss for field and armature with any given ratio of losses, the temperature arrived at would be correct, provided the temperature constants were obtained from experimental runs where the motor went through the same cycle as in the run to be determined.

Suppose we take our motor equipment, place it upon a car and run it over a measured length of level track, keeping an accurate record of the current input and voltage per motor at each instant. Then let this sample run be repeated successively for a period of ten hours, or long enough for the motor temperatures to reach their maximum, and we have the relation between energy lost in the motor and its temperature for a given set of conditions. Vary the length of the test run and repeat the ten-hour test and we have another relation between temperature rise and energy loss for another set of conditions. It is evident that a series of such tests taken on a given type of motor would give material from which the relation between its internal losses and temperature rise would be known for any set of conditions, and, moreover, these values could be used directly in calculations for any given service as they were obtained under operative conditions, and need no constant applied to make them approximately correct for service conditions.

It may be urged that it is difficult to reproduce with any accuracy the sample run agreed upon, or that it is difficult to follow through and keep an accurate record of just what takes place in the motor during its cycle of operation. If necessary, an automatic device for applying the current could be used, such as a

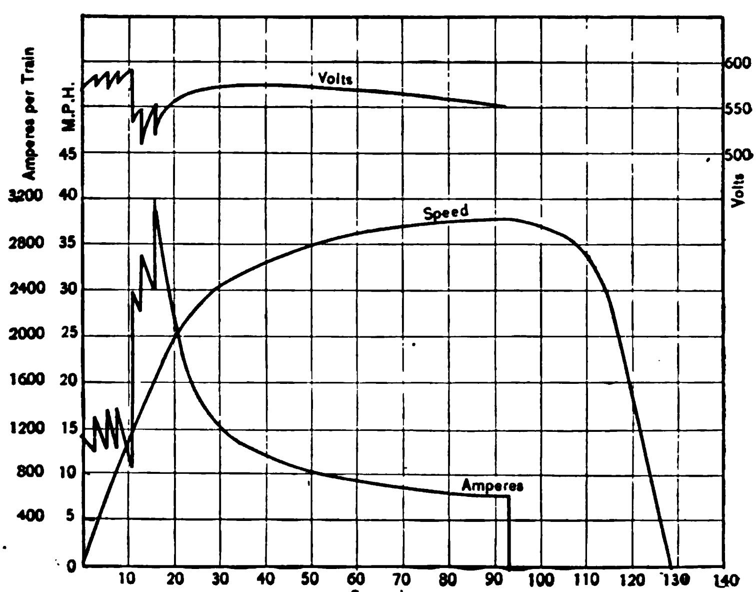


FIG. 4.

motor to throw on the controller at a predetermined speed. Sufficiently good results may be obtained, however, by ordinary hand control with a trained operator, while sample runs taken every few minutes by recording instruments, serve as a check and furnish the material upon which to base the motor's performance during the test.

A sample set of curves of such a test is shown in Fig.4, indicating voltage, amperes and speed upon a time basis, all taken by recording instruments. The voltage indicated is that between third-rail and ground, but the motor voltage during running upon resistance may be taken as proportional to its full internal voltage at the moment of cutting out final starting resistance, without making any appreciable error in arriving at iron loss values. The ampere curves give the means of determining the copper losses by plotting on polar coördinates as in Fig. 5, and determining the area by planimeter, giving directly the square root of mean square value. Both Fig. 4 and Fig. 5 show curves produced by a recording instrument placed directly in the main

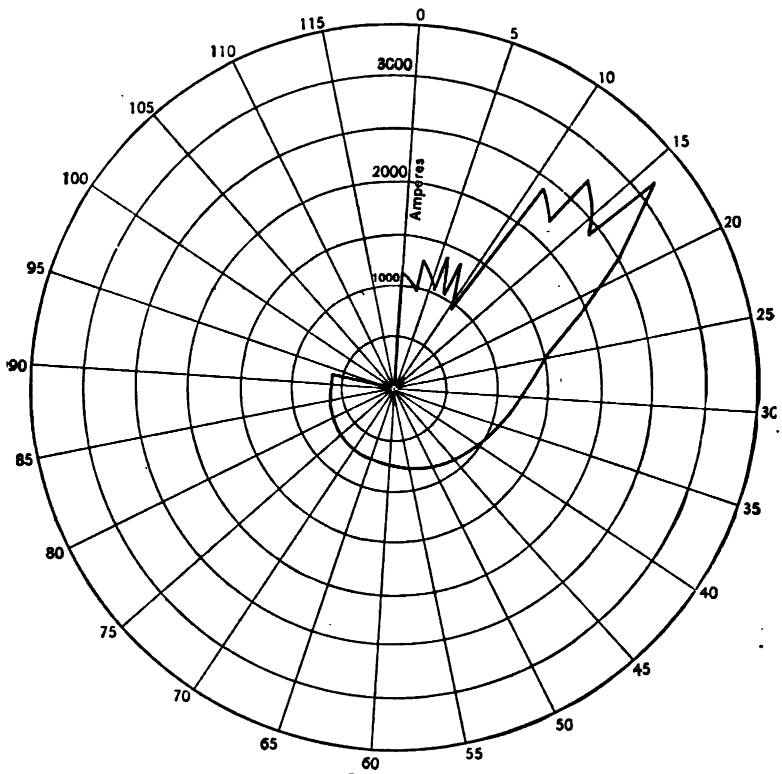


FIG. 5.

circuit of the car, thus giving the series parallel effect of the motors so connected. In our motor calculations we are concerned with the amperes per motor which will be independent of the series parallel control. The curves in Fig. 4 and Fig. 5, however, are shown simply to demonstrate the accuracy of the recording instrument, and while Fig. 5 could not be used directly to determine the square root of mean square current per motor, it shows the method used in determining this constant.

It will be seen that by using recording instruments and by taking a sufficiently large number of curves, it is possible to determine very accurately the average losses dissipated as heat by the motor during the test run, and also to ascertain the distribution of these losses in the several parts of the motor. The motor ventilation is the same as in a service run; it is operated at varying speeds, remains at rest the required proportion of the total cycle, and in every way the average conditions pertaining to a service run are reproduced in the test run, thus making the data so obtained directly applicable to service problems without the use of any constant.

A curve showing the results of a number of such tests is given in Fig. 6, indicating the degrees rise per watt loss in field copper

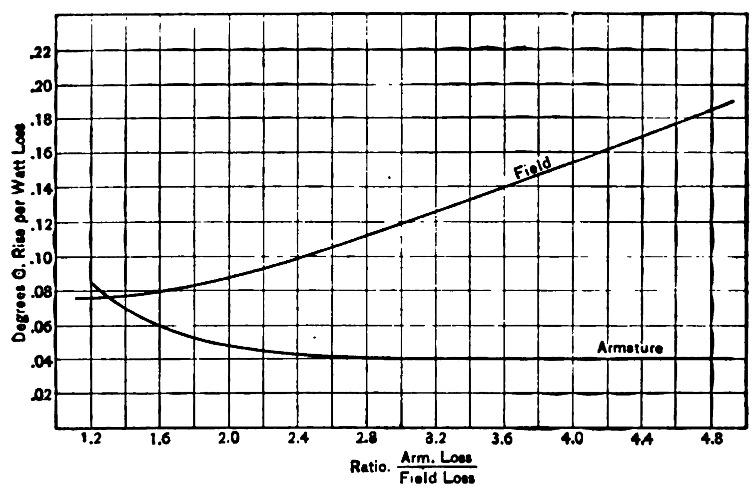


FIG. 6.

and in armature with any relation between total armature and field loss. Here also, the total iron loss is assumed to be in the armature, and this loss, added to that of the armature copper, gives its total loss, used in determining the ratio of losses.

Taking up again the study of the motors mounted upon the 25, 35 and 45-ton cars, we are now in a position to apply the motor losses obtained in Fig. 3 with the 35-ton car, and similar curves with the 25 and 45-ton cars. By completing the cycle in Fig. 2 and bringing the car to rest in any given distance, the time of shutting off power may be determined, the average losses and their distribution ascertained by curves in Fig. 3, and the temperature rise found out by applying the constants in Fig. 6. That is, for any given schedule, we may determine the temperature rise of field and armature for the three-car train weights and the given gear ratio assumed. By plotting a sufficient number of schedules, a curve similar to Fig. 7 will result, which affords a very interesting study.

Such a curve in lieu of a better name might be termed a " service capacity curve " of the General Electric " H " motor. It

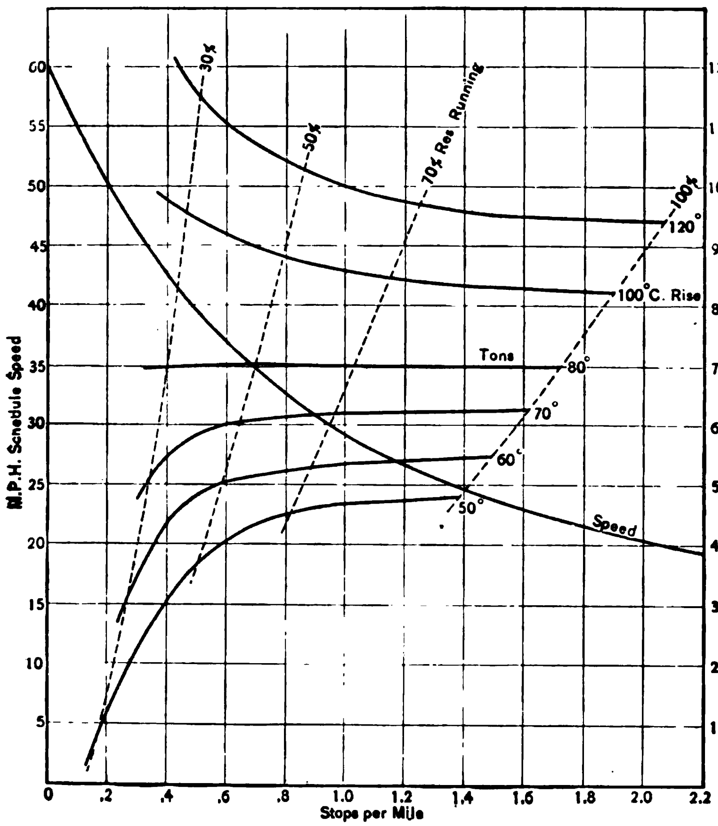


FIG. 7.

shows the temperature rise per motor for any weight of car and the schedule that can be performed with the gear ratio chosen, all plotted in terms of the number of stops per mile. The temperature rise is given as that of the hottest part, whichever it may be. The schedule includes stops lasting 15 seconds each. Acceleration is the result of a constant tractive effort of 120 lbs. per ton during resistance running, and braking is effected at the rate of 150 lbs. per ton. Coasting is assumed to continue 10% of the duration of the running cycle. Curves of higher temperature cannot be completed without greatly exceeding the commutation limit during acceleration, but would reverse and approach zero the same as those of lower temperature for infrequent stops.

The relation between train weight and temperature rise for a given schedule and frequency of stops is instructive. With one stop per mile and five tons weight per motor, a temperature rise of 54°C. is noted while ten tons per motor increases the temperature to 120°C. rise. That is, the motor temperature increases faster than proportionally to the increase in train weight, due, as we should expect, to copper losses increasing as the square of current; but our friction curves indicate a much larger friction in pounds per ton for the lighter weight cars, thus bringing the accelerating current required to propel a car at 60 m.p.h. to about that required for cars varying considerably in weight. We would expect, therefore, that for continued runs, where the losses due to acceleration are subordinated to the running losses, this increase in temperature with increased car weight would not be so marked. That such is the case is shown by comparing temperatures in the case of train weights of five and ten tons per motor with more infrequent stops, say one stop in four miles, giving temperature rises of 72° and 98° respectively for the same schedule of 48 m.p.h. The curve for 80° rise is very curious, as it indicates a constant weight train with our equipment, regardless of the frequency of stops, while higher temperatures increase and lower temperatures decrease the train weight with the infrequency of stops. The percentage of the time that motors are operating upon starting resistances is indicated by dotted lines.

Curves shown in Fig. 7 are all based upon the same gross tractive effect, giving practically the same rate of acceleration. It is evident that the same schedules could have been made with innumerable other accelerating rates, coasting less with the slower and more with the more rapid rates. In order to make our study of the " H " motor more complete, two sets of curves similar to Fig. 7 were plotted, the first with an accelerating rate of 90 lbs. per ton gross and 10% coasting, and the second with 120 lbs. per ton and 25% coasting, both making the same schedule with the same frequency of stops. The comparison of these two curves is shown in Fig. 8, plotted for a temperature rise of 60° only, in order to avoid confusion. The lower rate and less coasting has some advantage for more frequent stops, but as such an equipment would not be used geared for 60 m.p.h. with much less than a two mile run average, it follows that the temperature rise would be virtually the same with either rate of acceleration.

Lower speed equipments, however, present results differing from this, as is shown in Fig. 9, illustrating the 60° rise curve for

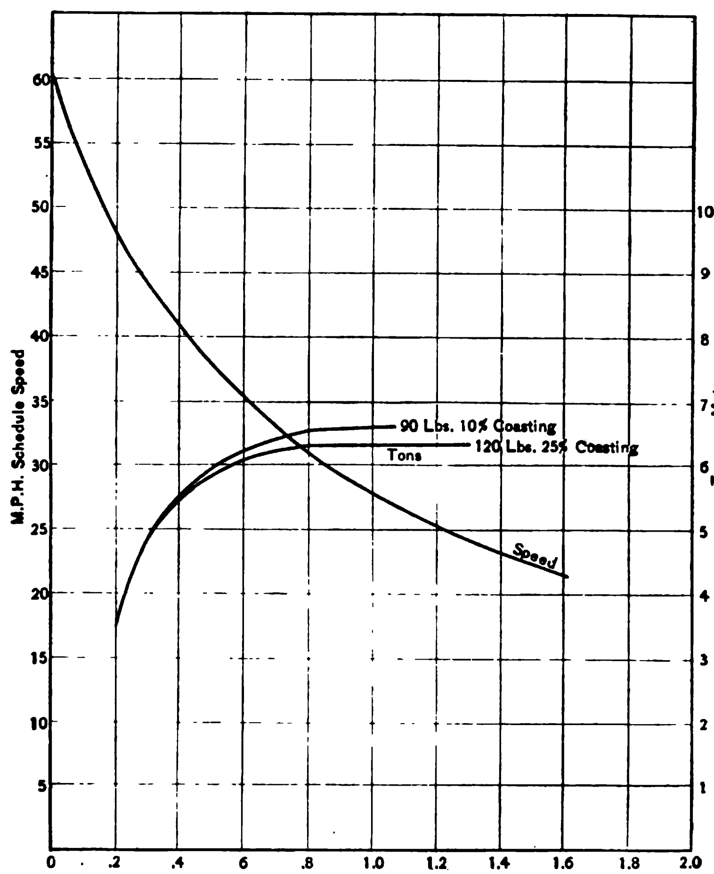


FIG. 8.

a maximum speed equipment of 30 m.p.h. Here 160 lbs. and 25% coasting contrast very favorably with 120 lbs.and10% coasting. In other words, the motor capacity is greatly increased by raising the accelerating rate while still maintaining the same schedule and frequency of stops. Increasing the accelerating rate does not necessarily mean going beyond the commutating limit of our motors, as a lower speed gearing can increase the rate of acceleration with the same current flowing in the motors as with the slower rate of a higher speed gearing.

A study of the foregoing curves seems to indicate that, so far as motor heating is concerned, it is preferable to use the largest gear ratio and highest rate of acceleration possible for the accomplishment of the service contemplated, provided the maximum

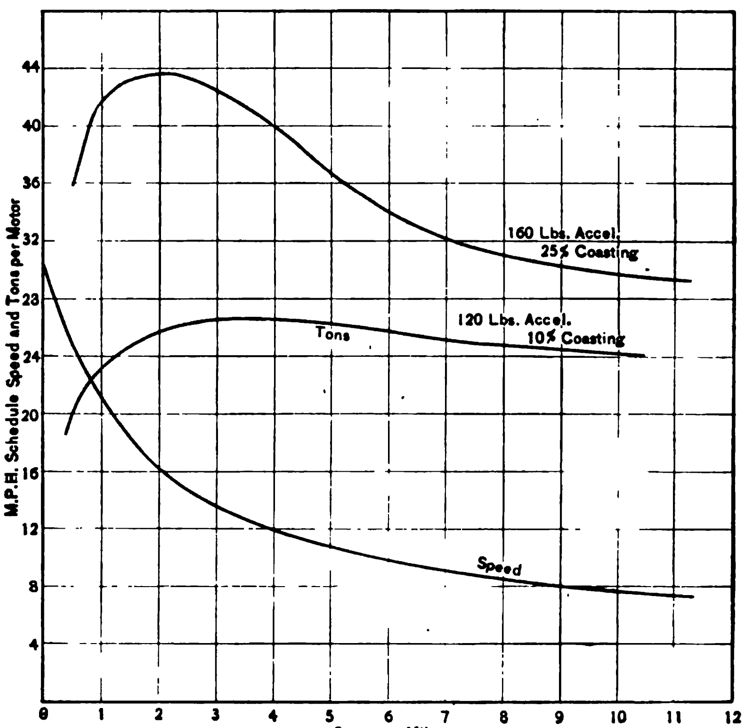


FIG. 9.

speeds are low, but that practically any rational rate of acceleration may be used where speeds approach a maximum of 60 m.p.h. As will be shown later, the energy consumption is less for a higher rate of acceleration permitting more coasting, but unfortunately the fluctuations on the distribution system and the load curve on the generating station may both be much poorer if the accelerating rate is carried too high and the number of units in service is small. In the choice of gear ratio for a given service, therefore, not only must account be taken of the question of motor heating with different rates of acceleration, but due heed must be paid to the question of line fluctuations, station load and energy input. It may be possible that what is gained in car energy by a more rapid acceleration, may be lost by the poorer coal economy resulting from a more irregular load curve upon the generating station.

So far we have considered the question of capacity of our " H "

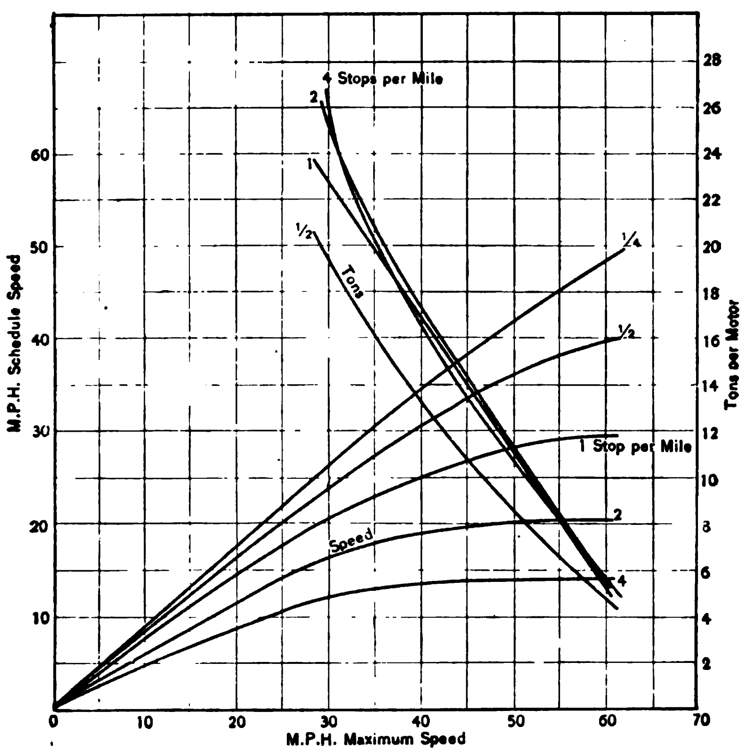


FIG. 10.

motor for one gear ratio only. It is obvious that similar calculations may be made for any other gear ratio corresponding to a different maximum speed on the level, and by combining the results of several sets of such calculations, it is possible to arrive at a capacity of our " H " motor for any schedule, any gear ratio and any frequency of stops. This may be plotted in terms of any temperature rise, and a set of such curves is plotted in Fig. 10 for a temperature rise of 60°. This set of curves still retains

120 lbs. per ton tractive effort, 15-second stops, 150 lbs. braking effort, and is based upon the performance of a single car using a four-motor equipment, following the lines of the friction curves given in Fig. 1. The relation between schedule speed and maximum speed on the level is shown with stops varying from one in four miles to four per mile, and the tons per motor for a maximum temperature rise in any part of the motor of 60° C. are shown from one stop in two miles to four stops per mile.

A careful study of the curves in Fig. 10 gives very interesting

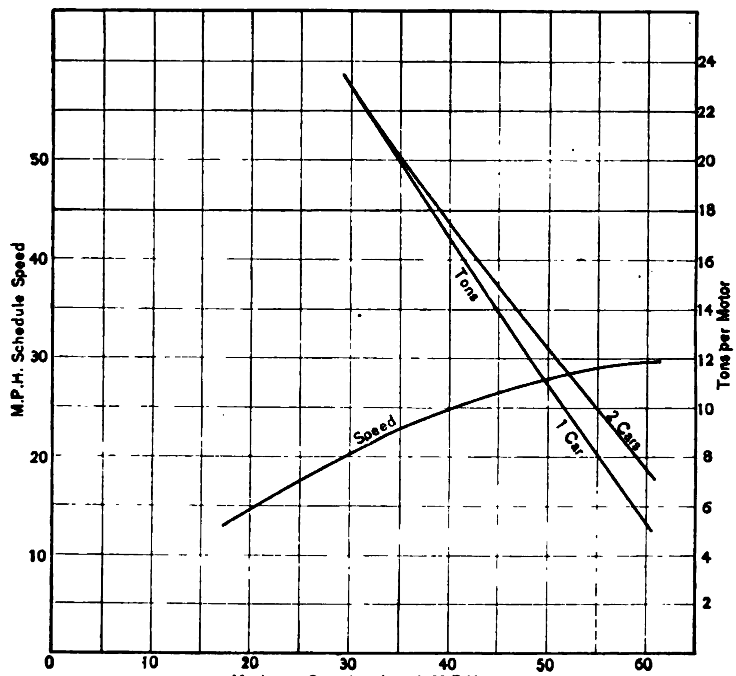


FIG. 11.

results. For instance, the "H" motor geared for 60 m.p.h. can operate between the limits of one stop in two miles and four stops per mile, making a schedule of from 40 m.p.h. down to 14 m.p.h., with approximately five tons per motor in all cases and the same temperature rise. In other words, an equipment of this character is protected from overheating by properly proportioning its gear ratio to the car weight. The possible schedule speed for a given gear ratio is controlled by the number of stops per mile, but the heating of the equipment, with the proper weight of car, will be the same over a very wide range of schedules and stops. The curves, also, bring out very forcibly the importance of properly gearing an equipment for the work which it has to do. For instance, a gearing giving 60 m.p.h. on a level track can make but 20.5 m.p.h. schedule with two stops per mile with a train weight of 5.6 tons per motor, while the same equipment geared for 47.5 m.p.h. can perform 20 m.p.h. schedule (practically the same), but can do so with a total train weight of 12.8 tons per motor, or more than double the train weight possible for the same temperature rise with the 60 m.p.h. equipment. In other words, the equipment should be geared for the lowest possible maximum speed that will permit the maintenance of the schedule in question, as a gear ratio giving too high a maximum speed for the work to be done not only overheats the motors, but produces needless demands upon the generating and distribution systems.

The curves in Fig. 10 give a fairly complete study of the type " H "motor when applied to the operation of single cars equipped with four motors. All points in the curve, except for a maximum speed of 30 m.p.h., are obtained with the operation of single cars, and as our friction curves may be inaccurate, being based upon a single set of tests, or trains of more than one car may be run, it is instructive to reproduce a similar set of curves for two, three, four cars, etc., per train. The motor capacity for a given temperature rise is governed largely by the shape of the friction curve used at high speeds, especially for the longer runs, and in Fig. 11 is shown a comparison between the operation of one and two-car trains making the same schedule, and using the same accelerating tractive effort per ton, braking and stop intervals as in Fig. 10. This set of curves is also plotted for a temperature rise of 60° C., but it is obvious that from the foregoing material we could plot similiar curves for any other temperature rise. As the curves showing the relation between tons per motor and maximum speed for a given temperature rise come so close together for the different frequency of stops, this sheet has considered only the relation between tons per motor and maximum speed for one stop per mile. Thus we see that at 60 m.p.h. the type " H " motor operating a single car has a capacity of but 5.3 tons per motor for 60° rise, while if two cars are coupled together and operated as a single train, the reduction in wind friction per ton of train weight increases the capacity per motor to 7.5 tons for the same 60° temperature rise, an increase of 42%. This opens up a new field of inquiry as to whether it is commercially advisable to run single car units at this high speed when the motive power, and as it will be shown later on, the energy input, are both larger than would result from operating the same seating capacity in trains of two cars or more, with a correspondingly increased time interval between trains. In other words, is the electric traction idea of small units at frequent intervals a proper method of attacking the very high speed electric traction problem, or are we compelled to go back to the steam method of operating heavier trains at more infrequent intervals, in order to prevent a prohibitive investment in motors, and generating and distributing systems, and a ruinous expense for operation? It is true that the electric system, being eminently adapted to subdivision, has created a demand for travel, by means of its frequent service, where none previously existed, but it may be possible that for very high speed work too great a price may be paid for the privilege of operating very frequent small units.

The foregoing discussion has described a method of determining the probable heating of a given motor when operated under any known conditions. The results obtained are so complete and give such a mass of working data directly applicable to service requirements, that the labor of the detailed calculations necessary seems amply justified. Specifications of stationary apparatus are prepared in careful detail and acceptance tests carried out with great exactness, but the tendency to slight the railway motor problem, owing largely to its seeming complexity, is hardly warranted, when it is considered that the capital invested in such apparatus may be double that required for generator power to drive it. Then, too, the generator is carefully housed, provided with an attendant and otherwise taken care of, while the motor is exposed to outside climatic conditions and only gives evidence of being overloaded by burning out. The selection of such apparatus should receive the most careful attention, the proposed service conditions fully worked out and the proper size of motor and correct gearing chosen to ensure a reasonably small expense for maintenance.

The present method of rating railway motors is to determine the current which they will carry at 500 volts on a stand test giving a temperature rise of 75° C. in the hottest part after sixty-minutes' run. In other words the one-hour rating of railway motors gives only an indication of the comparative capacity of two motors in actual service, and affords no data to serve as the basis of calculating the service capacity of the motor. It does determine the mechanical qualities of the motor, as the one-hour test is generally very severe, and it also affords a means of observing commutation at the maximum current for which the motor will probably be called upon in service operation. Some method of rating railway motors which would give an accurate comparison of their service capacity under different conditions, if such a rating is possible, would be of great advantage over the present very general one-hour rating.

The foregoing investigation has pointed out the very variable nature of the work which a railway motor has to do, and the different relations between service performed, distribution of losses and the ultimate heating of the motor. In Fig. 3 the various motor losses are shown for the type " H " motor taken as an example, but it is evident that different motor loss curves, even for the same service performed, could not be compared directly with any assurance of arriving at their comparative temperature rise. Proceeding further, we come to the values given in Fig. 6, showing the relation between motor losses, their distribution, and the resulting temperature rise per watt loss. Similar curves of different motors could be compared directly and give some means of determining their relative capacity, but here, also, there is no direct comparison, as different motors do not have the same efficiency, and therefore will not give the same loss for the same service performed. In other words, given two motors having the same thermal constants, that is, the same degrees rise per watt loss, the motor having the poorer efficiency will rise to a higher temperature for the same service performed, owing to its greater loss. We cannot, therefore, look to the thermal curves as giving the comparative rating needed.

In Fig. 7 we have a fairly complete history of the type " H " motor operating under a given set of assumptions. These assumptions are those pertaining to service operation, and such a set of curves for another motor calculated for the same conditions would give accurately the comparative size, or in other words, the comparative temperature of the two motors for the same service performed. In Fig. 7, the " service capacity curves " approach much nearer to a basis of comparing different motors, but as a method of rating railway motors it is incomplete. In the first place, we have assumed a given rate of acceleration, while it is obvious that the demands of different classes of service, especially low-speed service, will call for different rates of acceleration, and hence a separate sheet would have to be made out for every rate of acceleration. The effect of increasing the rate of acceleration and increasing the time of coasting is shown in Fig. 9, giving such discrepancy between tons per motor for a given temperature as to make sheets similar to Fig. 7 entirely unreliable for comparing different motors, especially when the maximum speeds are low and the acceleration energy is the determining factor in the motor heating.

There is another variable, the rate of braking, which has not been entered into in this discussion, and which also affects the heating of the motor, especially on low-speed, high-acceleration problems. On the higher speed problems, where friction is the ruling factor, it is found that we must also assume a certain friction rate, or in fact a friction curve plotted to a definite formula, in order to arrive at consistent results with different motors. Having once determined on this friction curve for a single car, our calculations are immediately disqualified when we couple two of these same cars together and perform the same service, the friction rate at speeds of 50 or 60 m.p.h., falling off considerably as we approach a train composed of several units.

In addition to the foregoing variables, we have the element of the energy consumed by the rotating parts during acceleration. This factor is practically negligible at very high speeds, but figures very prominently in acceleration problems with low speeds. In giving the rating of a railway motor, it will be necessary, therefore, to fix definitely upon the weight and center of gyration of car wheels and armatures, and furthermore to determine the effect of the motor parts for a given gear ratio.

After all these variables are definitely fixed, we must repeat the same set of conditions for each motor gear ratio, or, as a more general case, for each different maximum speed on level, thus eliminating the question of the total number of teeth in gear and pinion. It is not intended in any way to discourage an effort to rate a railway motor by some method that will give its comparative capacity, but it is well to canvass carefully the large field of variables which must enter into such a rating, and to have clearly in mind the bearing which these different variables have in determining the temperature of the motor. It is evident that by affixing certain values to accelerating rate, train friction, braking effort, energy of rotating parts, etc., it will be possible to prepare a set of curves giving the relation between schedule, frequency of stops and temperature rise for any car weight, which would give accurately the comparative size of a railway motor in relation to any other motor for which curves were similarly plotted. Such work is being done by the General Electric Company on its standard railway motors, and in fact is necessary in order to be able to give the probable performance of a motor under any set of conditions and to follow through the effect of changing the conditions. The method, however, is cumbersome, and has so many factors entering into the case that it probably may never serve as a commercial rating; furthermore, such relation could only be expressed by curves, or a long, tabulated statement, and neither method is short and concise enough for a commercial rating.

As the result of considerable investigation along these lines, the writer has not arrived at any commercial rating of a railway motor which serves its purpose better than the one-hour test now universally used. Admitting that such a test does not give the comparative size of different motors, it does serve the purpose of largely determining its commutating qualities and possesses the advantage of being commercial. Unless a rating can be proposed which will indicate accurately the relative size of motors, the present method of one-hour rating possesses advantages which would hardly warrant its being superseded.

Although insufficient data is at hand from the foregoing calculations to form the basis of a complete treatise on the subject of train energy, sufficient material is provided to furnish some very interesting comparisons. As the basis of calculations, we assume the operation of single car trains composed of 25, 35 and 45-ton cars, geared for a maximum speed of 60 m.p.h. for the 35-ton car. From our friction curves we find that these three cars at 60 m.p.h. require a tractive effort of 59 lbs., 50 lbs. and 43.5 lbs. per ton respectively. The same calculations were carried through for trains composed of two cars or more, the cars being of different weights, so that we were able to plot a set of curves showing the relation between schedule speed and watt hours per ton mile input to the train, virtually ignoring any fixed formula for train friction. Such a set of curves is shown in Fig. 12, being plotted for 30, 40, 50 and 60 lbs., per ton friction rate at 60 m.p.h. These curves may be regarded as fairly general in their scope, except that they follow the general form of the friction curves given in Fig. 1. In other words, we can get from these curves in Fig. 12, the energy consumption for any friction rate at

60 m.p.h., the error introduced by assuming a general shape of curve being very small.

An inspection of Fig. 12 brings out forcibly the fact that the subject of car energy at high speed is most intimately interlinked with the question of train friction. As the schedule speed decreases with the increasing number of stops, or in other words, as the energy of acceleration becomes a more important factor, the per cent. difference between the energy values for different train frictions becomes less, as would be expected.

The electric road has almost universally used one car units, and as it has branched out into suburban high speed work, the

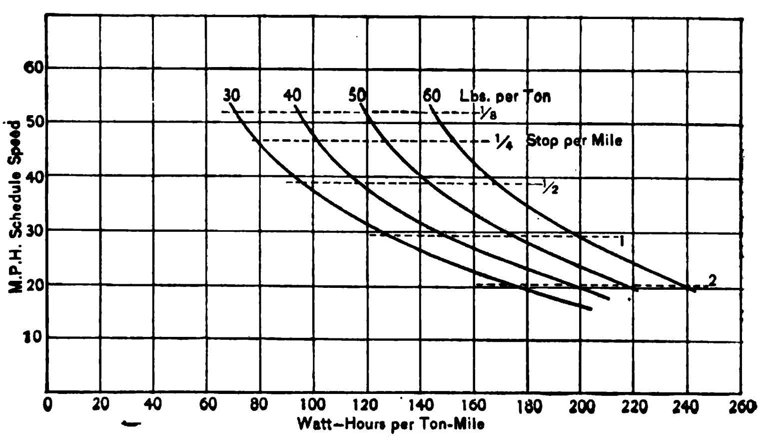


FIG. 12.

advantages of more frequent service have made the operators of such roads retain the single car idea. From the curves given in Fig. 12, some figures may be obtained of what it costs to operate a single car, and also trains of two or more cars, where the maximum speed is 60 m.p.h., and the stops very infrequent; that is, the more advanced type of our private right-of-way suburban roads. A single 35-ton car having a friction, say, of 50 lbs. per ton at 60 m.p.h., will consume 119 watt hours per ton mile at a schedule of 52 m.p.h. with one stop in eight miles. Let two such cars be coupled together in a train, reducing the friction to 33.5 lbs. per ton, and the train will require an input of only 78 watt hours per ton mile, or 65.5% of the energy rate per ton required in single car operation. In other words, single cars on 30-minute headway would require 52.5% more energy for their operation than would two-car trains on one-hour headway.

With five-car trains composed of 35-ton cars, the energy is reduced to 56 watt hours per ton mile for the same schedule, or less than half what will be required per ton for the operation of single car trains.

From a purely energy standpoint it would seem that the operation of single-car trains was disadvantageous, but experience has shown that it is not fair to assume that two cars operated every hour will attract the same custom as one car operated every thirty minutes. In other words, the frequency of service creates travel and in many cases warrants the extra expenditure for coal. There is another aspect of the case to be considered and that is, that with two-car trains at more infrequent intervals the load upon the feeding points is more fluctuating, the size of

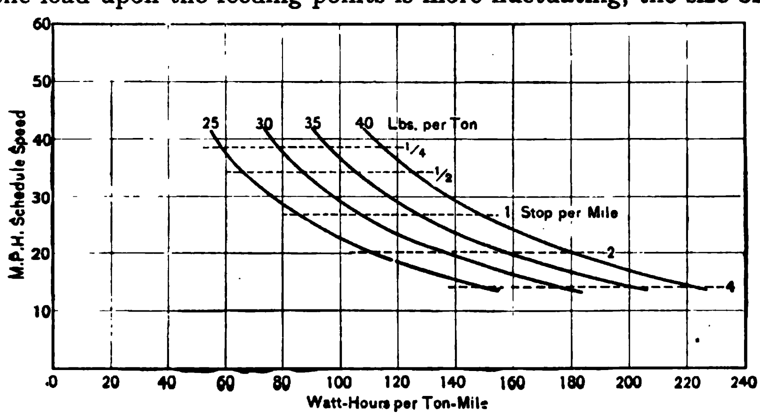


FIG. 13.

rotary converters must be somewhat increased, and in all probability a larger amount of feeder copper will be required to keep the drop within the same limits. Although a saving may be effected in the coal pile by increasing the train headway and giving the same seating capacity in trains of two or more cars, there is every reason to expect a call for a greater expenditure of money to install the road, and an increase in interest and maintenance account that may go far toward eating up the saving in the fuel expense.

In Fig. 13 and Fig. 14 are given curves showing the relation between schedule speed and train energy for maximum speeds of 45 and 30 m.p.h. respectively. It will be noticed that, particularly for 30 m.p.h. maximum speed, the train friction becomes a very much smaller factor in determining the energy input, especially as the number of stops per mile increases.

All these three sets of curves are plotted for an accelerating rate corresponding to 120 lbs. per ton, and a braking effort of 150 lbs. per ton. The values given will, therefore, be subject to considerable variation for different accelerating and braking efforts where the schedule speed is low and stops numerous. The curves are, however, of fairly general use, especially for runs of a mile or more, as the effect of the rate of acceleration and braking is not so marked on longer runs.

In Figs. 12, 13 and 14 is considered, also, a period of coasting equalling 10% of the time the train is in motion. While this is a fairly general assumption and will give sufficient margin

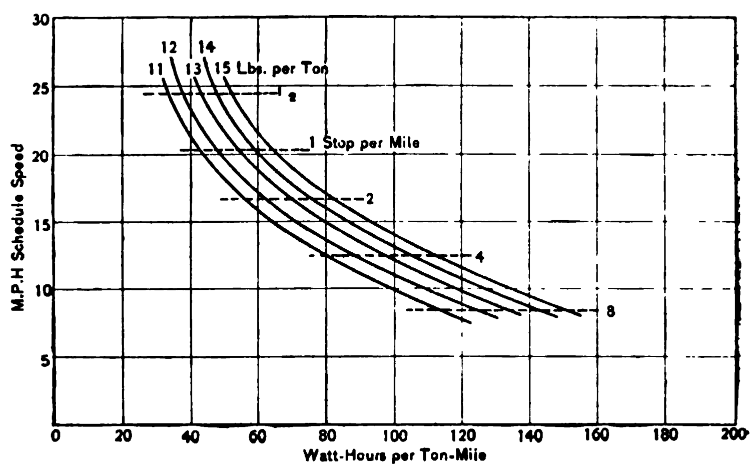


FIG 14.

for a large majority of problems, it will be found in carrying out the subject to a conclusion that the per cent. of coasting is a very large factor in determining the train energy input. For instance, a high rate of acceleration with a long period of coasting will demand less energy input to the train than a lower rate and little or no coasting. The reason for this is obviously that the efficiency of acceleration of the two runs may be approximately 70%, while the speed at which brakes are applied is less with a longer coasting period, and hence the work demanded by the equipment is less.

In all three of the energy curves given, a variable friction during acceleration and coasting is considered, but straight line braking is assumed. The energy required to accelerate the rotating parts is also considered, so that the curves as given are of fairly general application.

In this paper the writer has attempted to outline a method of determining the probable heating and energy consumption of a given equipment for any class of work, having in mind, also, the possibility of arriving at some short, concise method of rating different railway motors, so that their comparative service capacity might be accurately indicated. As the subject of motor capacity is so dependent upon experimental tests, not only of car friction and braking, but also of heat radiation under working conditions, the conclusions drawn were based so far as possible upon actual experiments made. Were it not for the fact that car friction, or rather train friction, is such a variable quantity, dependent not only upon the condition of track but upon the speed and composition of the train, it would be possible to plot a set of curves for a given friction and distance, and apply these curves for similarly shaped runs over greater or less distances by taking the coördinates proportional to the square root of the area of the speed-time curves; that is, proportional to the square root of the distances covered. As, however, the wind friction at the higher speeds changes the value of friction per ton to such an extent, it is only possible to draw up curves for a given set of conditions and generalize, as is done in Figs. 12, 13 and 14 for different friction rates.

While it is thus possible to prepare a set of energy curves which are of fairly general application to all problems, it is only feasible to express the relation between motors of different capacity by a series of curves similar to those described in Figs. 7, 8, 9 and 10. It is entirely possible to approximate the probable heating of motors of different sizes when the resistance, core loss and general construction are known, but such short-cut methods are at best only approximations and no true comparison of different motors can be made which will take into account their different losses for the same work performed and their capacity for radiating these losses at different speeds, without considering the subject in detail for each motor alone along the general lines indicated in this paper.

In dealing with the railway motor where the temperatures approximate 60° C. rise in practice, with an air temperature in summer reaching 30° to 35° C., we have not much leeway below a temperature injurious to the insulation, and approximate methods giving rise to errors of 10° or 20° C. in temperature cannot be seriously considered in such important calculations as the determination of railway motor temperatures. For this reason the methods outlined, although entailing a large amount of experimental work and subsequent calculations, provide an accurate method of determining the temperature of railway motors operating under any known conditions, and although they fail to provide a method of rating railway motors, it is due to the fact that such a method of rating cannot be expressed by any short term, but necessitates some such general curves as are indicated in the paper.

The writer wishes to acknowledge the services of Mr. E. F. Gould in preparing material for this paper, and the kindness of the General Electric Company in furnishing results of experimental tests which served as a basis of all calculations.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 19th, 1902.

COMPARATIVE ACCELERATION TESTS WITH STEAM LOCOMOTIVE AND ELECTRIC MOTOR CARS.

BY B. J. ARNOLD AND W. B. POTTER.

In connection with the preparation of a report on the use of electricity for the propulsion of trains of the New York Central Railroad in the tunnel entrance and terminal in New York City, an invitation was extended by the General Electric Company to Mr. W. J. Wilgus, Chief Engineer of the railroad company, to use its experimental track (Fig. 1), and apparatus at Schenectady, and a series of tests were accordingly carried out under the direction of the authors of this paper. The tests were principally for the purpose of determining the comparison between steam and electric traction on short-haul suburban passenger service. Owing to the short curves in the connecting tracks, the General Electric Company's track could not be used for the steam locomotive tests. The steam tests, therefore, were made on the New York Central main line tracks west of Schenectady.

The steam locomotive shown in Fig. 2 was built from the specifications of Mr. A. M. Waite, Superintendent of Motive Power and Rolling Stock of the New York Central, by the Schenectady Locomotive Works. It was designed specially for the rapid acceleration work required in suburban service, being provided with large grate area and heating surface and a very large proportion of weight on its driving wheels.

The two electric motor cars were similar in form, 54 feet over all, each weighing about thirty-five tons including the electrical equipment, which consisted of four "G. E. 55" motors and type M. control. All axles being equipped with motors, the two cars together gave approximately the same weight upon the drivers as the steam locomotive. The acceleration was, therefore, directly comparable for trains of equal net weight, and to secure this comparison the same trail cars arranged in the same order were used in both the steam and electric tests.

In the steam runs the draw-bar pull, speed and time were recorded by an Illinois Central dynamometer car, and the same car was used with the electric motor cars to determine the relation between current input and draw-bar pull. The dynamometer car had to be returned before the electric runs were completed, but not before a large number of readings were taken, from which curves were plotted showing the relation between amperes and draw-bar pull with different weights of train behind the motor cars. The draw-bar pull thus determined has been plotted on the attached electric motor car curves, which were taken subsequent to the return of the Illinois Central car.

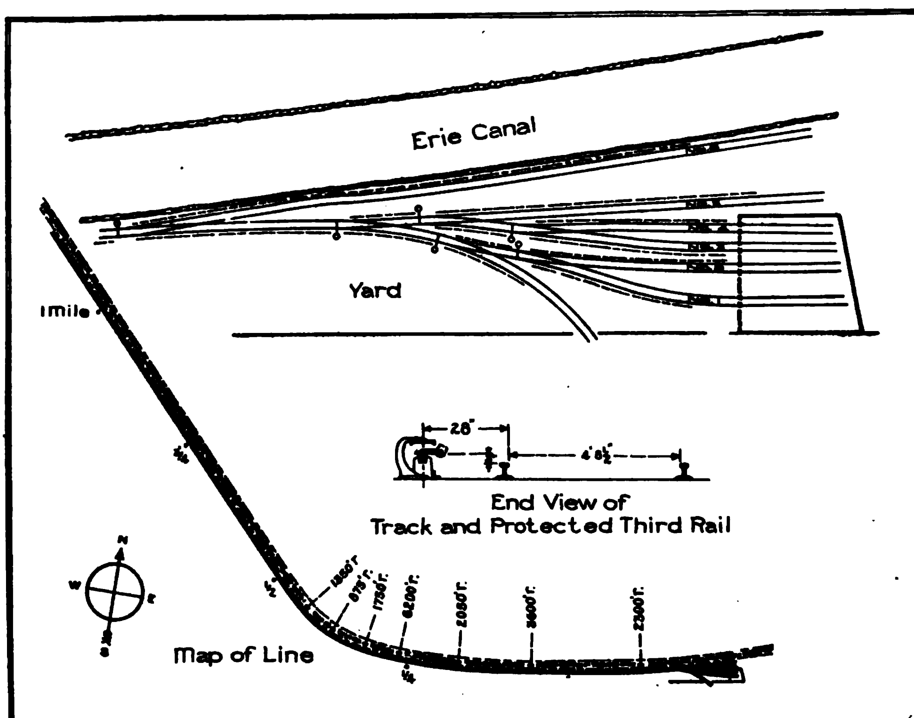


FIG. 1.—Map of General Electric Railroad.

The order of the tests, both steam and electric, was as follows: A train of six cars, including five standard passenger coaches lent by the New York Central Railroad, and the dynamometer car, was started and run over a mile of track, acceleration being made as rapidly as possible with the power available. These same runs were repeated, dropping off one car at a time, until only the dynamometer car remained. Automatic records were kept of the draw-bar pull, speed, time, distance and the strength and direction of the wind. The condition of rail and the temperature were also noted. The same runs were repeated, using the two motor cars in place of the steam locomotive, the dynamometer car being used in some of the runs and a box car loaded to equal weight in subsequent runs. In

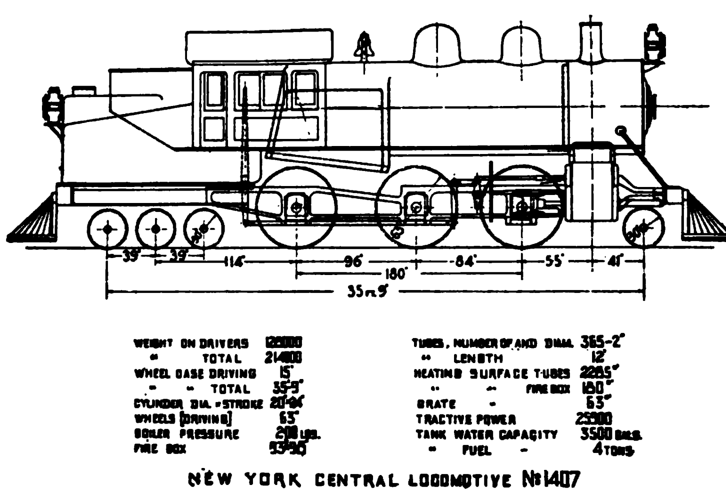


FIG. 2.—Outline of Steam Locomotive No. 1407.

the electric runs, additional records were kept of voltage, ampere and wattmeter readings. The wattmeter was not carried on the car, but was placed stationary at the point of feeding the third rail, thus avoiding any inaccuracy due to jarring. The voltage leads of the wattmeter were connected to the extreme end of the third rail and track, thus receiving at all times the exact voltage at the train, so that the energy delivered to the motor cars represented the net input and did not include losses in the feeder system.

The cars used in this test and the weights are given below:

New York Central locomotive	No. 4107	214,000	lbs.
General Electric motor car	No. 4	73,000	lbs.
General Electric motor car	No. 5	70,000	lbs.
Illinois Central dynamometer car	No. 17	45,640	lbs.
New York Central coach	No. 1885	48,200	lbs.
New York Central coach	No. 545	60,250	lbs.
New York Central coach	No. 1709	53,700	lbs.
New York Central coach	No. 508	51,450	lbs.
New York Central coach	No. 1798	54,600	lbs.

During the tests many runs were made, but for the illustration of this paper, representative and average runs only are given.

Electric Motor Cars Nos. 4 and 5.

The electric runs were made upon the General Electric experimental track against a head wind of 15 m.p.h. The rail was dry, the temperature 8° C., and the grade practically level. In the middle of the run there was a curve having a minimum radius of 875′, equivalent to about a 6½° curve, the friction effect of which may be assumed as approximately equivalent to one-tenth per cent. up grade of the steam runs.

No. of run.	Character of load.	Weight of load, tons.	Total weight train, tons	Maximum speed.	Average speed.	Watt hours per ton mile. From volt amperes.	Watt hours per ton mile. From watt-meter.
1	6 Trailers.	157.	228.5	36.4	27.2	75.9	79.4
3	5 "	130.	201.5	37.9	28.6	78.4	82.0
5	4 "	104.	175.5	39.1	29.8	84.3	86.9
7	3 "	77.	148.5	41.0	30.6	84.7	93.4
9	2 "	47.	118.5	42.8	32.0	98.5	99.4
11	1 "	23.	94.5	44.7	33.1	115.0	114.0
13	No "		71.5	46.7	34.6	132.3	129.0

New York Central Steam Locomotive No. 1407.

All steam locomotive runs were made upon the New York Central main line track west of Schenectady, against an up grade of .1% and a head wind of 15 m.p.h. The temperature was 4° C. and the rail wet with a very light falling snow.

No. of run.	Character of load.	Weight of load, tons.	Total weight of train, tons.	Maximum speed. m.p.h.	Average speed. m.p.h.
2	6 Trailers.	157.	264.	39.0	28.2
4	5 "	130.	237.	41.3	28.4
6	4 "	104.	211.	40.9	27.4
8	3 "	77.	184.	45.7	27.3
10	2 "	47.	154.	48.0	30.1
12	1 "	23.	130.	50.9	33.0

Although this locomotive was especially built for suburban or acceleration work, and was provided with a large fire-box, giving it facilities for rapid steaming, the pressure dropped from 200 lbs. to less than 185 lbs., during the first part of acceleration. In starting, the throttle was opened wide and steam used full stroke, the engine being hooked up as acceleration proceeded. Curves showing detail of these runs are given in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

While the electric runs had the advantage of dryer rails than the steam runs, the driving wheels were not slipped in either instance. Although the steam locomotive was able to give a maximum tractive effort at starting equal to that obtained electrically, this high tractive effort was not maintained, but immediately fell with increased speed, even with the most expert handling.

As the acceleration curves produced by the steam locomotive and electric motor cars have different shapes, and as in the two tests there was about the same weight upon the drivers, it is interesting to note how well this driver weight was utilized. This is shown by the following tables giving the speed reached in ten, twenty and thirty seconds with equal trailing load for both electric and steam trains.

MILES PER HOUR ATTAINED IN 10 SECONDS.

No. of trailers	1	2	3	4	5	6
Motor cars Nos. 4 and 5	22.5	20.7	17.3	14.4	12.6	11.2
Locomotive No. 1407	14.	13.	12.5	12.	10.	9.7

MILES PER HOUR ATTAINED IN 20 SECONDS.

No. of trailers....	1	2	3	4	5	6
Motor cars Nos. 4 and 5	34.	32.3	29.4	27.4	24.5	21.2
Locomotive No. 1407	25.	21.2	21.5	19.5	18	16.3

MILES PER HOUR ATTAINED IN 30 SECONDS.

No. of trailers................	1	2	3	4	5	6
Motor cars Nos. 4 and 5	38.2	36.4	34.2	32.4	30.3	28.1
Locomotive No. 1407	31.7	26.2	27 2	24.7	23.2	20.3

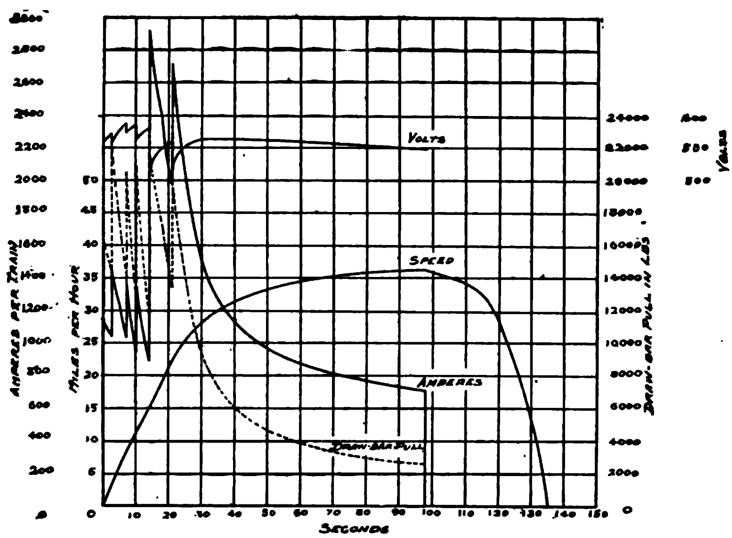


Fig. 3.—Electric Run No. 1. 6 Trail Cars—Weight 157 tons. Including Motor Cars 228.5 tons. Power on 4170 ft. Distance Run 5380 ft. Watt hours per ton mile 79.4.

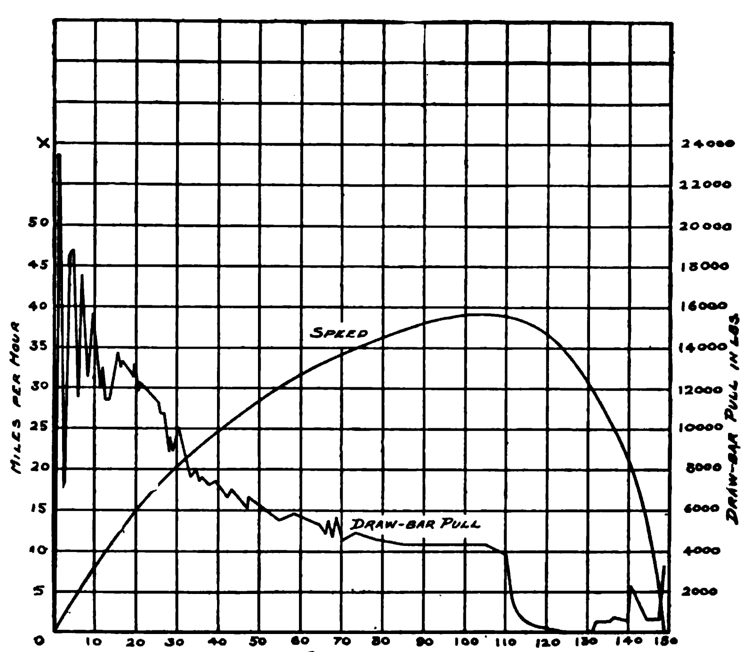


Fig. 4.—Steam Run No. 2. 6 Trail Cars—Weight 157 tons. Including Locomotive 264 tons. Power on 4035 ft. Distance Run 6150 ft.

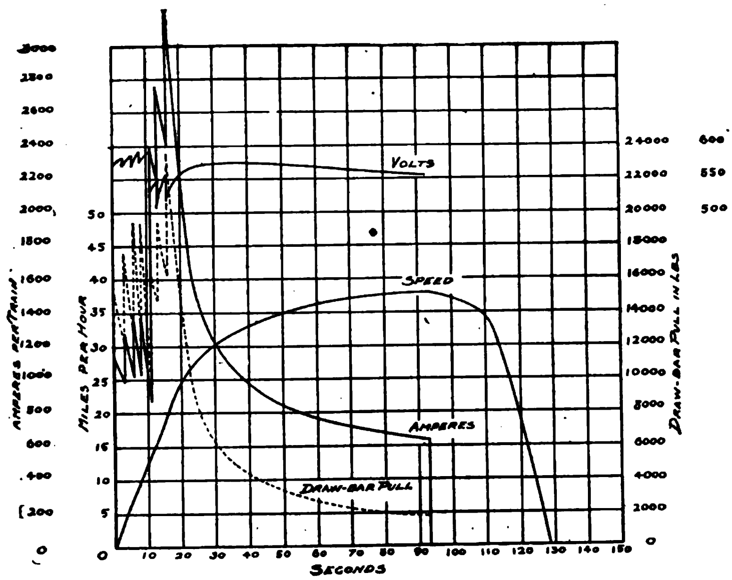


FIG. 5.—Electric Run No. 3. 5 Trail Cars—Weight 130 tons. Including Motor Cars 201.5 tons. Power on 4170 ft. Distance Run 5380 ft. Watt hours per ton mile 82.

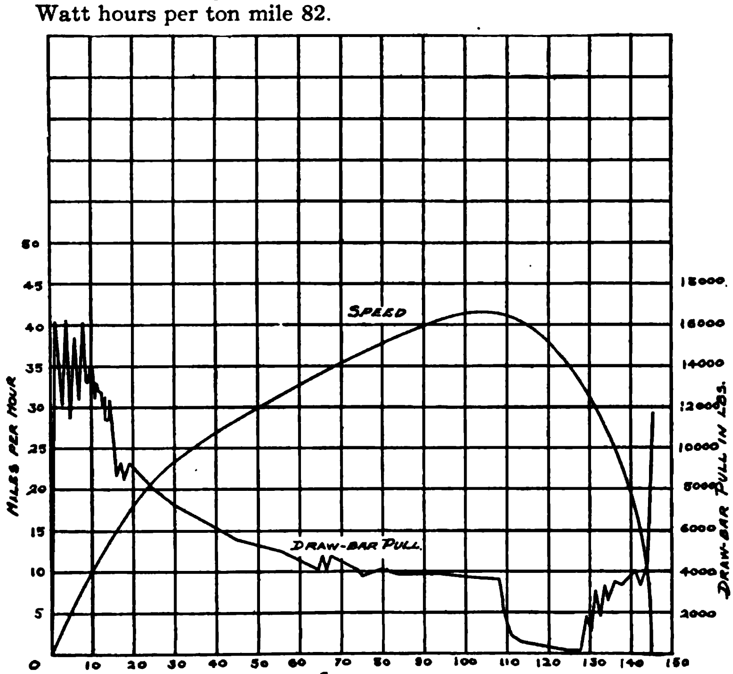


FIG. 6.—Steam Run No. 4. 5 Trail Cars—Weight 130 tons. Including Locomotive 237 tons. Power on 4270 ft. Distance Run 6050 ft.

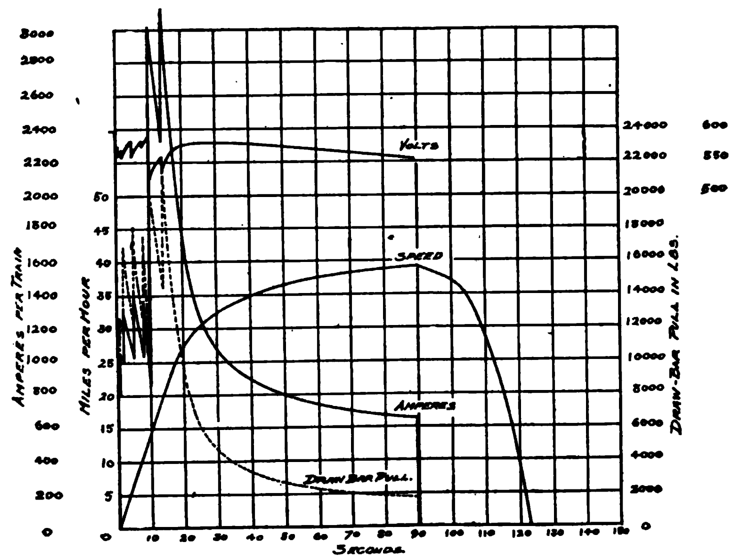


Fig. 7.—Electric Run No. 5. 4 Trail Cars—Weight 104 tons. Including Motor Cars 175.5 tons. Power on 4135 ft. Distance Run 5380 ft. Watt hours per ton mile 86.9

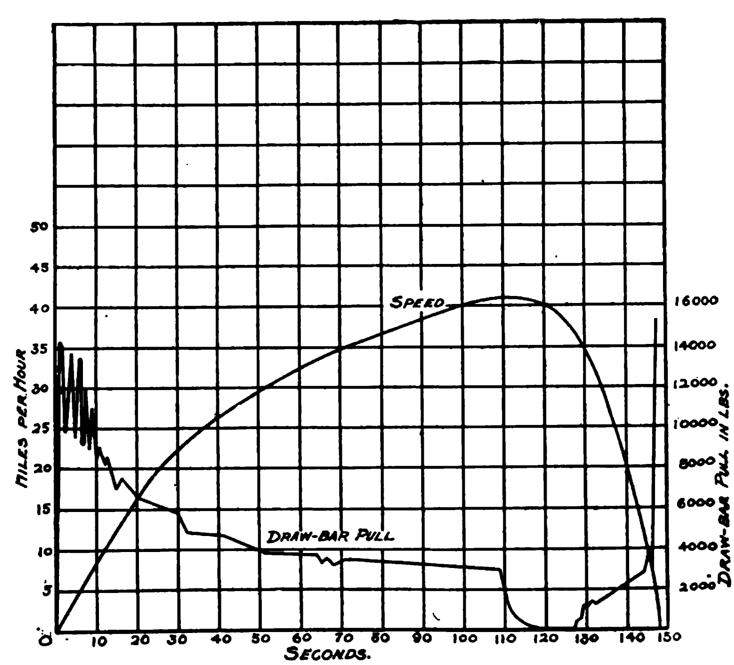


Fig. 8.—Steam Run No. 6. 4 Trail Cars—Weight 104 tons. Including Locomotive 211 tons. Power on 4490 ft. Distance Run 5943 ft.

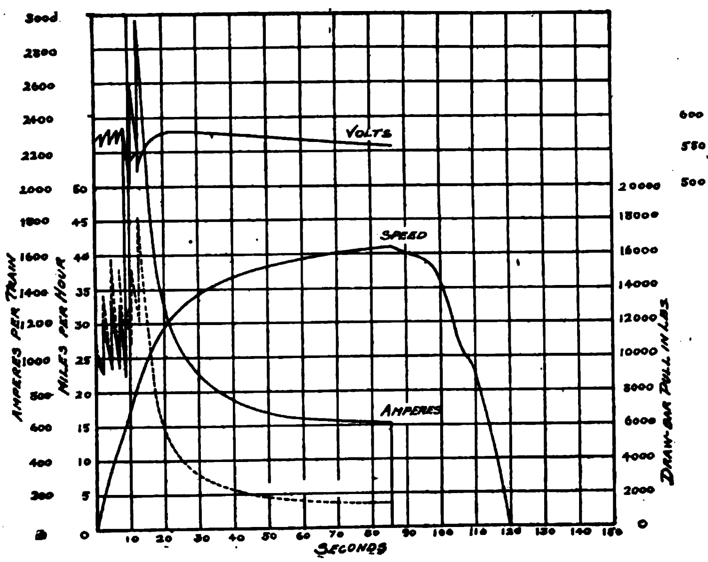


FIG. 9.—Electric Run No. 7. 3 Trail Cars—Weight 77 tons. Including Motor Cars 148.5 tons. Power on 1470 ft. Distance Run 5370 ft. Watt hours per ton mile 93.4.

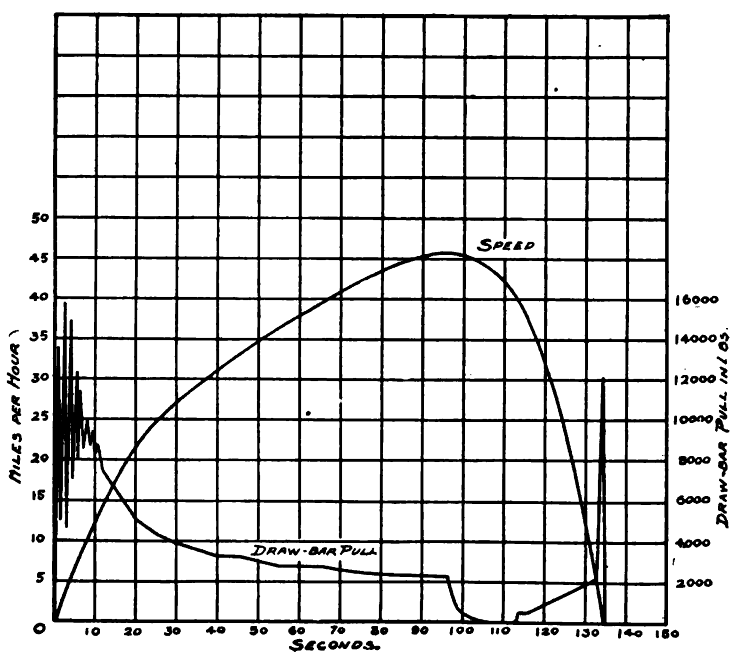


FIG. 10.—Steam Run No. 8. 3 Trail Cars—Weight 77 tons. Including Locomotive 184 tons. Power on 4520 ft. Distance Run 5980 ft.

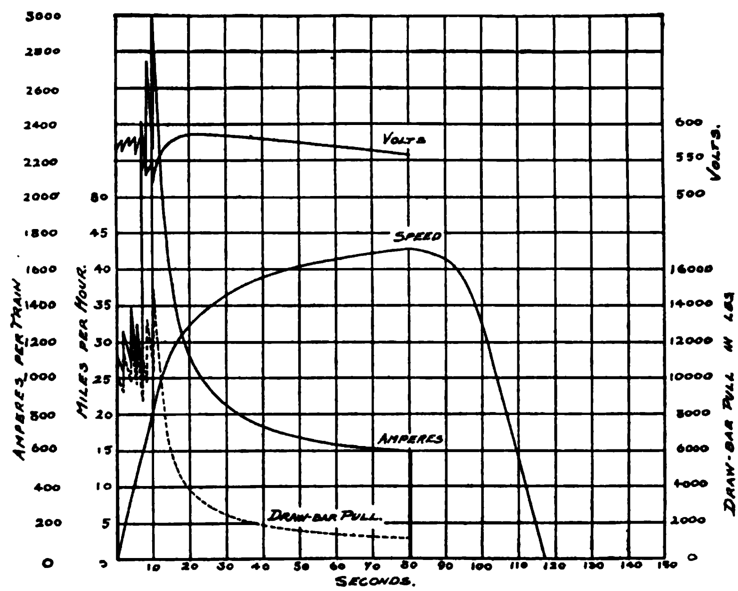


FIG. 11.—Electric Run No. 9. 2 Trail Cars—Weight 47 tons. Including Motor Cars 118.5 tons. Power on 4100 ft. Distance Run 5490 ft. Watt hours per ton mile 99.4.

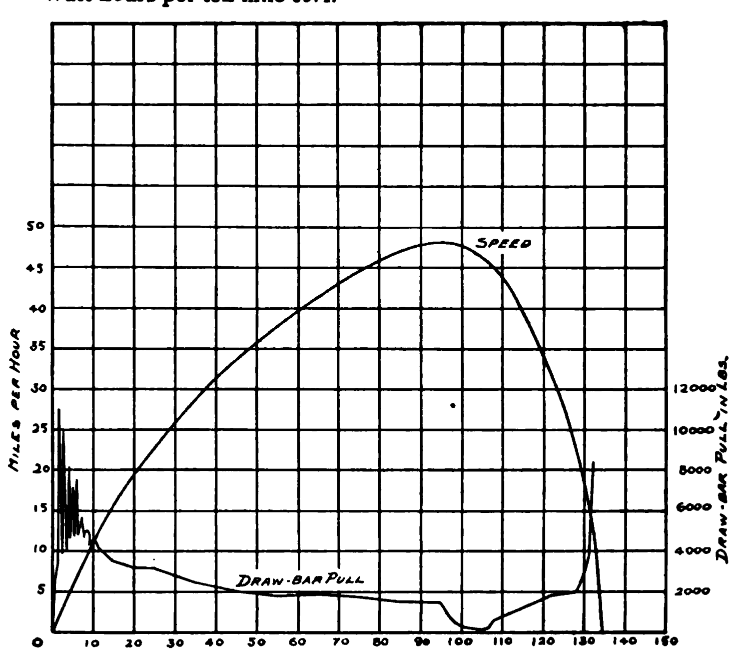


FIG. 12.—Steam Run No. 10. 2 Trail Cars—Weight 47 tons. Including Locomotive 154 tons. Power on 4455 ft. Distance Run 5927 ft.

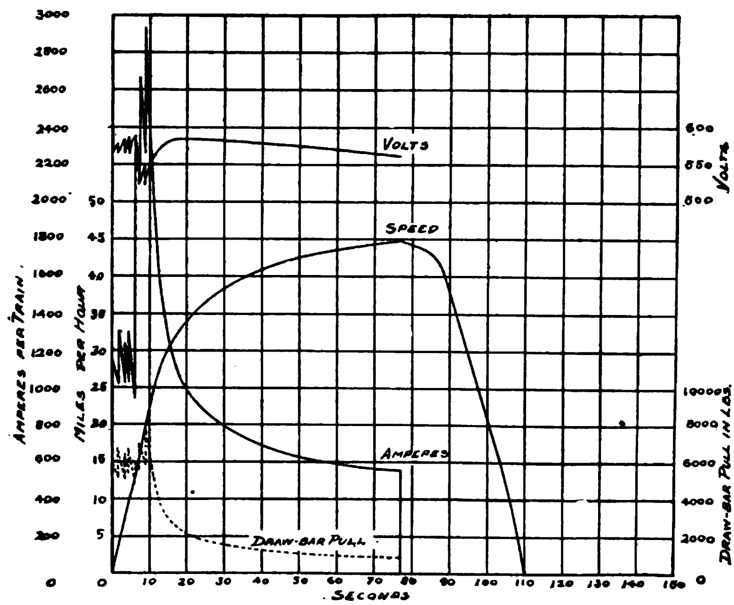


Fig. 13.—Electric Run No. 11. 1 Trail Car—Weight 23 tons. Including Motor Cars 94.5 tons. Power on 4060 ft. Distance Run 5850 ft. Watt hours per ton mile 114.

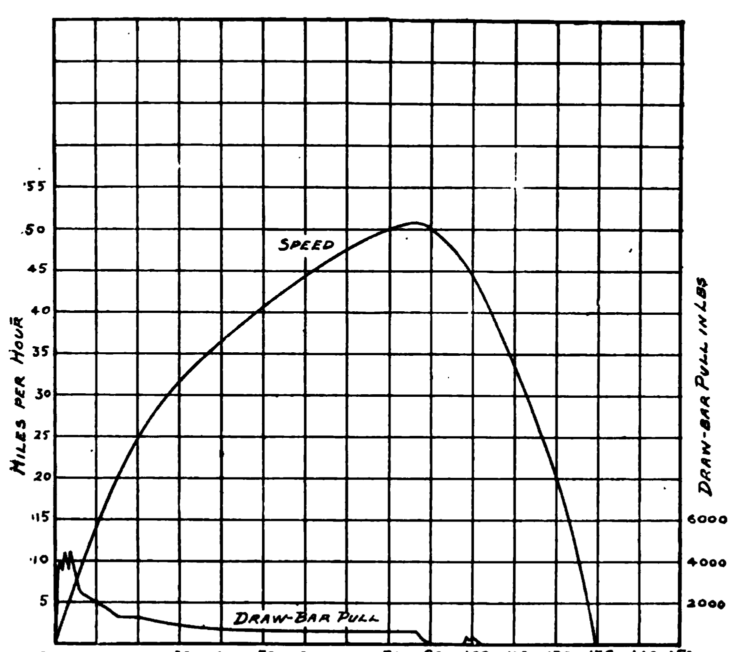


Fig. 14.—Steam Run No. 12. 1 Trail Car—Weight 23 tons. Including Locomotive 130 tons. Power on 4160 ft. Distance Run 6260 ft.

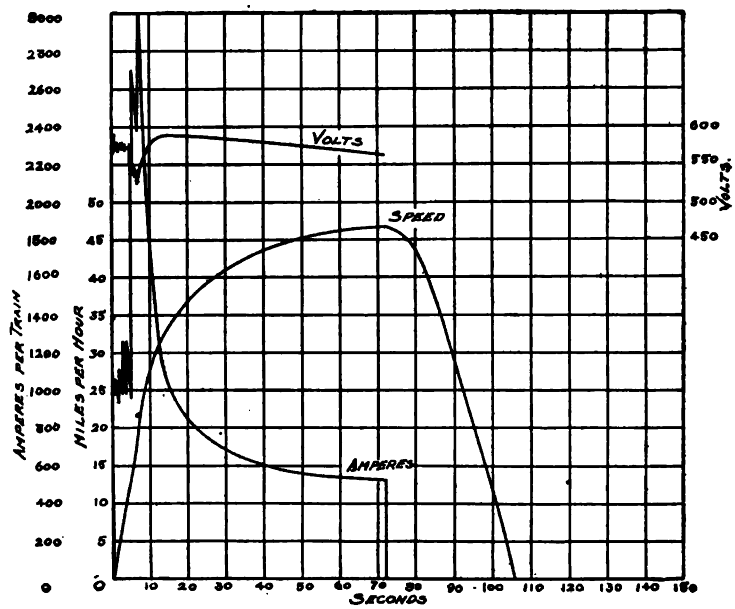


FIG. 15.—Electric Run No. 13. No Trailers. Motor Cars 71.5 tons. Power on 4080 ft. Distance Run 5360 f . Watt hours per ton mile 129.

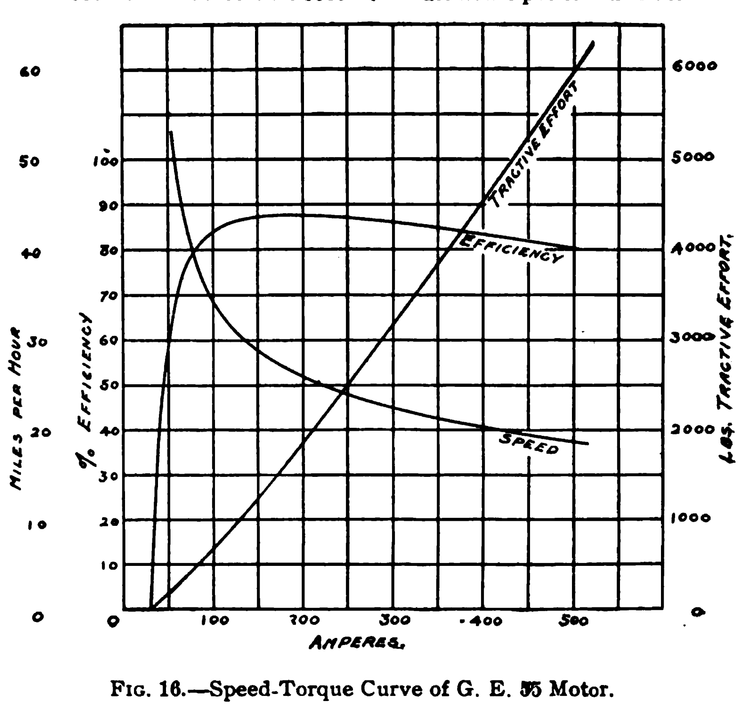


FIG. 16.—Speed-Torque Curve of G. E. 55 Motor.

An inspection of the above tables clearly brings out the fact that the electric motors during acceleration can more effectively utilize the weight upon their drivers than can a steam locomotive. As rapid acceleration is especially important when stops are a mile or so apart, the electric motor has an advantage in being able to cover the same distance in the same time with less energy expended and at less maximum speed than a steam locomotive, owing to its being able to maintain its maximum accelerating rate for a longer period.

The average speed given in both steam and electric tables is the average speed of the train while it is in motion, and does not include time of any stop at the end of the run. Starting from rest, the power was kept full on to the three-quarter mile post where the power was shut off and the brakes applied in such a manner as to bring the train to rest as near the mile post as practicable. In the tests the steam train ran from 5 to 15% over a mile before the train was brought to rest and the electric trains from 2 to 4%, but even with the longer distance the average speed of the steam runs only approached that attained in the electric runs made over a shorter distance. A comparison of the two sets of runs on the basis of average speed is, therefore, not quite fair to the electric motor car, as its average speed would have been considerably higher if the length of the run had been the same as that made with the steam locomotive. An inspection of the tables will show, however, that even with the shorter distance run, the electric motor cars were able to make higher average speeds than the steam locomotive over its longer distance, and these higher average speeds were obtained also with a lesser maximum speed.

The maximum speed of a train making a given run in a given time serves as an indication of its energy consumption. A train, therefore, which is so handled as to make a given run in a given time, with lowest maximum speed, will consume less energy for the run. The electric runs tabulated all show a lower maximum speed and a higher average speed than those runs made with the steam locomotive, and the energy consumption of the electric runs should, therefore, be less for the same service performed than with the steam locomotive.

The motors of an electrically equipped train may be placed upon the trucks of ordinary passenger coaches, each carrying its full complement of passengers, and thus lessen the gross weight by elimination of the locomotive. The true measure of comparison between steam and electrically propelled trains should be the energy per seat mile rather than per ton mile, as

FIG. 17.—General Electric Railroad.

the latter value is based upon the total train weight and includes a considerable proportion of dead weight embodied in locomo-

FIG. 18.—Electric Motor Car, No 4.

tive and tender. The steam locomotive not only adds to the train weight, the weight necessary to ensure traction, but is further handicapped by additional weight on pony trucks and usually a tender.

FIG. 19.—General Electric Railroad Yard.

As an illustration, the following table has been prepared from these tests showing the number of cars in the train, the number

FIG. 20.—Train Used in Electric Tests.

of passengers carried (each car seating 64 persons) and the energy, which for convenience we have given in watt hours, required per passenger for both steam and electric runs.

NET ENERGY PER PASSENGER CARRIED.

Number of Cars.	Number of Passengers.	Watt Hours per Passenger Steam.	Electricity.
6	384	43.9	29.7
5	320	52.2	32.1
4	256	57.5	33.5
3	192	77.4	37.5
2	128	103.0	45.2
1	64	187.8	45.2

This table is based upon the actual net energy delivered to the wheels of the train and does not include the losses inherent to any system of operation. The results tabulated may, therefore, be considered as fundamental, and typical of the two systems of operation—the steam locomotive and the electric motor car.

The following table gives the efficiencies for the seven electric runs, the efficiency being the ratio between net energy output to the wheels and total volt-ampere input:

EFFICIENCY OF ELECTRIC RUNS.

Trailers.	Average m. p. h.	Watt hours per ton mile, Output.	Input.	Efficiency, of run.
6	27.2	59.1	79.8	74. %
5	28.6	61.0	82.0	74.3%
4	29.8	63.8	84.9	75.3%
3	30.6	68.0	90.2	75.3%
2	32.	69.6	99.6	69.9%
1	33.1	75.3	112.8	66.7%
0	34.6	79.8	130.0	61 5%

An accurate comparison of the relative efficiency or coal consumption of steam and electric power for similar service would require an extensive series of tests with indicator and dynamometer on the performance of the steam locomotive.

As a matter of interest we have obtained an approximate comparison from a single test by weighing the coal and water taken by steam locomotive No. 1407 for a period of 24 hours, covering four trips between North White Plains and Grand Central Station, a distance of 24.75 miles, on the Harlem Division of the New York Central Railroad. The trips occupied about 4 hours, the yard movements about 1 hour, and the locomotive was idle for 19 hours.

Following is a detailed record of the service covering the 24 hours:

NORTH WHITE PLAINS TO GRAND CENTRAL STATION.

Time.	Number of Cars.	Number of Stops.	Total Weight.	Weight of Cars.	Effective. h. p. h.
63.5 min.	8	21	204 tons	97 tons	129
Lay-over....................	6 hours.				

GRAND CENTRAL STATION TO NORTH WHITE PLAINS.

Time.	Number of Cars.	Number of Stops.	Total Weight.	Weight of Cars.	Effective. h. p h.
66.25 min.	5	17	278 tons	171 tons	255
Lay-over........		12 hours.			

NORTH WHITE PLAINS TO GRAND CENTRAL STATION.

Time.	Number of Cars.	Number of Stops.	Total Weight.	Weight of Cars.	Effective. h. p. h.
60.3 min.	7	13	387 tons	280 tons	251
Lay-over......................		¾ hour.			

GRAND CENTRAL STATION TO NORTH WHITE PLAINS.

Time.	Number of Cars.	Number of Stops.	Total Weight.	Weight of Cars.	Effective h. p. h.
59.75 min.	4	20	256 tons	149 tons	246
Lay-over............		1¼ hours.			

Total effective h.p. hours, hauling coaches 861
Coal consumed .... 13,412 lbs
Coal per effective h.p. hour ....15.6 "

The effective h.p.h. given above, is the energy required for movement of the cars only, exclusive of the locomotive, and was determined from the draw-bar pull taken by dynamometer car in previous tests over the same route.

The coal consumption covers all coal burned during the period of 24 hours, not only for movement of cars, but also movement in the yard and the banking of fires during lay-overs.

The effective h.p.h. to move the cars serves as the basis of comparison with electric service, the coal consumed by the locomotive for whatever purpose being properly chargeable to the net work done by the locomotive during the period.

The efficiency of an electrical system, as an average under variable load, may reasonably be assumed as follows:

Engine	90%	Efficiency	
Alternator	92%	"	
High Potential Transmission	98%	"	
Transformers	97%	"	
Converters	92%	"	
Third Rail	95%	"	
Motors, including control................	75%	"	51.33%

This percentage of effective horse-power output of motors to i.h.p. of engine will vary somewhat, depending on the load factor. As an even figure we will assume an efficiency of 50%.

Coal consumption per indicated h.p.h. from actual records of electric power stations, is in some cases less than 2 lbs., the average being about 2½ lbs. At the latter figure, the coal per effective h.p.h. output of electric motors would be 5 lbs. Assuming the head end air resistance as 10% and as the electrical equipment would increase the weight of the cars about 20%, the actual comparison of coal consumption would be approximately in the ratio of 6.6 for electric and 15.6 for steam.

Assuming that coal for a power station may be purchased for 80 per cent. of the cost per ton of that used in the locomotives, and that the cost of coal for electrical power is about one-third of the total cost, including maintenance and interest on investment, it is probable that the actual gross cost of electrical power would closely approximate the coal consumption of a steam locomotive in this class of service, the maintenance of the electrical equipment and attendance required being, however, considerably in favor of the electric power.

We wish to express our thanks to Mr. E. C. Schmidt, Professor of Railway and Mechanical Engineering, University of Illinois, for his able management of the dynamometer car, assisted by Messrs. J. J. Snodgrass and R. W. Lohmann; also to Messrs. A. H. Armstrong and E. F. Gould of the General Electric Company for their careful supervision and calculations of the electric tests.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 19th, 1902

AN EXPERIMENT WITH SINGLE-PHASE ALTERNATORS ON POLYPHASE CIRCUITS.

BY C. O. MAILLOUX.

An experiment of considerable theoretical and practical interest, incidentally illustrating the elasticity of the polyphase current system, was recently tried successfully at Phœnix, Arizona. This experiment was a practical demonstration of the possibility of using single-phase alternators as the source of energy for supplying polyphase currents, both two-phase and three-phase, and also for supplying direct current to a transmission and distribution system. The experiment was conducted at Phœnix on April 7, 1902, by the writer, assisted by Mr. D. W. Beldon, the electrical engineer of the Phœnix Light and Fuel Company, of Phœnix, using the machinery and facilities of the old steam station and of the new transformer sub-station of that company. A summary description of the plant will be useful in explaining the conditions of operation and the circumstances leading to and attending the experiments made.

About three years ago the Phœnix Light and Fuel Company entered into negotiations with the Arizona Water Company, which controls the irrigation canals and the water used for irrigation in the Phœnix Valley, or that portion thereof lying north of the Salt River, for the exclusive privilege of utilizing for water power purposes 'all water controlled by the Arizona Water Company. In the summer of 1899 a commission of engineers, including the writer, selected sites for two water power stations, the locations being fixed at such points that the water could be utilized for power purposes without detriment to its subsequent use for irrigation.

The designs for the two power stations and for a receiving or transformer station, were completed by the writer, and contracts were made about a year ago. The first station was completed and put in operation in April, 1902. This station is situated on an Indian reservation about 24 miles east of Phœnix. It comprises two generator units, each of 200 kilowatt capacity, each belted to a separate turbine.

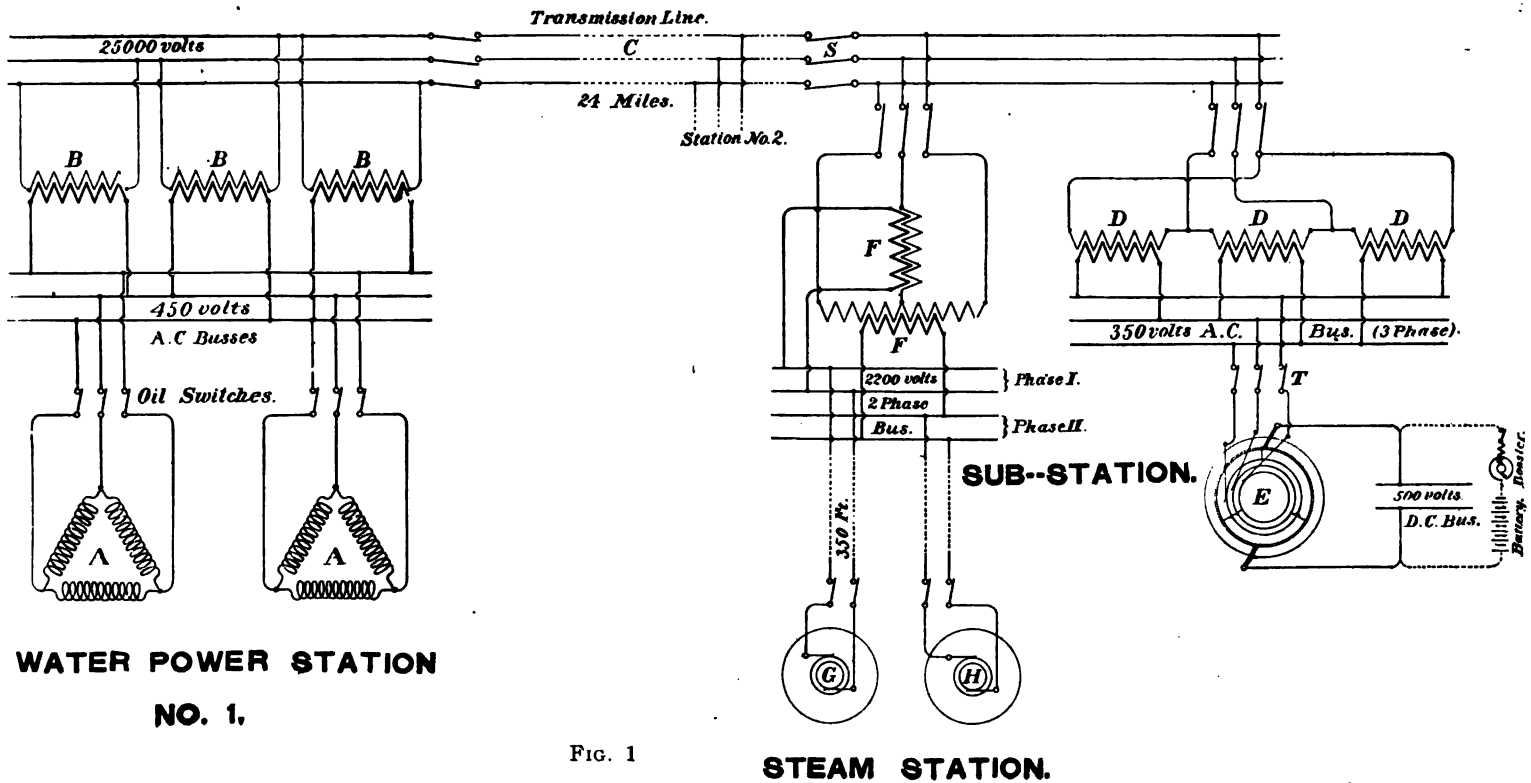
Station No. 2, now in process of construction, is located at the Arizona Falls, at a point about nine miles north-east of Phœnix. This station is expected to be completed about August 1st. The design of this station is substantially the same as that of station No. 1, but the two generator units have only half the capacity, 100 kilowatts. The aggregate normal capacity of both stations will be 600 kilowatts. The turbine capacity is 1.75 h.p. per kilowatt, or 1,050 aggregate h.p.

The transformer sub-station is located in a new building on the same plot of ground as the old steam plant of the company, but at a distance of about 300 feet from it. This station is the receiving point for the electrical energy to be generated at the two power stations. The transmission line (three wires, copper, No. 6 B. and S.) runs from Station No. 1 past Station No. 2 where it makes a loop connection. The two stations are to be operated in parallel.

The system uses three-phase transmission, delivering energy at about 22,500 volts at the transformer station, where there are two sets of lowering transformers, including those for lighting current service, which are of the Scott three-phase, two-phase, type, stepping down from three-phase, 22,500 volts, to two-phase, 2,250 volts; and those for the power current service, of the ordinary type, stepping down to three-phase, 350 volts, for supplying the rotary converters, of which there will be two, each 150 k.w. The frequency used is 60 cycles per second.

The company purposes to furnish alternating current for lighting and power from the two-phase, 2,200 volts, feeder lines, and also direct current for power purposes only, at 500-550 volts. for operating street railway motors, elevators and for supplying power for various large and small customers. The power current system is to be supplemented by a storage battery having a capacity of about 300 k.w. hours.

The old steam generating plant, which is to be discarded



Transmission Line.
25000 volts
C
S
24 Miles.
Station No.2.
B
B
B
450 volts
A.C Busses
Oil Switches.
A
A
WATER POWER STATION
NO. 1.
F
F
2200 volts
2 Phase
Bus.
Phase I.
Phase II.
350 Ft.
G
H
STEAM STATION.
D
D
D
350 volts A.C.
Bus.
(3 Phase).
T
E
SUB--STATION.
500 volts.
D.C. Bus.
Battery.
Booster.

Fig. 1

after the new plant is completed, is composed of three high-speed steam engines, driving two arc light dynamos, and three single-phase monocyclic alternators. Two of the engines are each belted direct to one alternator and one arc light dynamo. The three alternators, respectively of 50, 75 and 100 k.w. capacity, are operated as "single-phasers," the "teaser" circuit being discarded; and they have never been operated in parallel, each having been used to supply current to distinct sets of feeders at an e.m.f. of about 2,200 volts for incandescent lighting, through transformers, 2,200–104 volts, in the usual way.

Fig. 1 shows diagrammatically the system and equipment at the first generating station (No. 1) and at the sub-station. A A represent the two three-phase generators; the exciters, with their circuits and connection and all indicating instruments, being omitted. B B B are the three raising transformers. C is the transmission line extending from station No. 1 past station No. 2 to the sub-station, being controlled by the line switches at the point of entrance in the sub-station, and by similar switches at each power station. D D D are the three three-phase lowering transformers for the rotary converters E (only one of the two converters being as yet installed). The D. C. leads of the rotary connect with the D. C. switchboard bus-bars. F F are the lowering transformers of the Scott type, which receive three-phase current from the transmission line and deliver two-phase current to the lighting feeder bus-bars. G and H represent two of the single-phase alternators located in the steam generating station, which were used for the experiments to be described.

Various causes, the principal one of which was the delay in the shipment and delivery of machinery, have contributed to retard the completion of the generating stations, the first being at least four months and the second about seven months behind the date of completion originally expected.

With both water power stations in operation, the power supply is likely to be adequate for the electrical load carried at all times, except in the very low water period, or from about the middle of May to the middle of July. As the second station is not now likely to be completed in time for the low water season, it became necessary to anticipate a shortness of water power and to consider the best ways of utilizing the existing steam plant as a supplemental source of power capable of operating in conjunction with the first water power station, and even of replacing it altogether. and of alone carrying the load wholly or in part, if necessary, in case of emergency.

The high cost and low quality of fuel here, of course, make it desirable to reduce the hours of operation of the steam station to the lowest number possible. With this object in view, arrangements have been made to carry the entire incandescent lighting load from the sub-station whenever possible. It is the intention, as soon as the necessary apparatus can be procured, to replace the present arc lights, series direct current open arc system, with the alternating current enclosed arc system. For the present the arc light circuits are to be fed from the existing arc light dynamos, driven either by the present steam engines, when water power is insufficient, or else by motors taking electric power from the sub-station, when the water power is ample, the motors being so placed that the change in driving power for the dynamos may be quickly made by merely changing the belts from the engine to the motor pulley.

There were two problems to be considered: First, the problem of running the incandescent lights partly or wholly from the steam-driven, single-phase alternators; second, the problem of generating direct current for the power circuit and for charging the battery so as to use it for peaking the load, and also for using it in emergencies, the battery being especially useful when the power available is at the lowest point. The expedient of transferring some of the lighting feeders from the two-phase bus-bars in the transformer station to one or more of the three single-phase alternators in the steam station, was resorted to provisionally, but it involved too much complication in switches and manipulation to be desirable or trustworthy as a permanent feature. Arrangements were therefore made for coupling the single-phase alternators, each with one phase of the two-phase bus-bars in the sub-station. The necessary connections having been made, and a Lincoln synchronizer having been procured and connected, the experiment of coupling first one, then another of the alternators in multiple with either of the two phases was tried, the alternator being brought to the synchronous speed by regulating the engine throttle-valve. The next step was to connect one of the alternators with each phase. This was easily done. There was no difficulty in making the alternators keep in step, and in making them carry a proportion of the total load. It was also found, as was to be expected, that the alternators could be utilized in balancing the two phases, in case they were unequal in potential difference, owing to unequal loads.

The first problem, therefore, being solved by these experiments, the second problem was then taken into consideration. A little thought showed that the rotary converter, if kept running by the electric current from a storage battery, could be used and could be depended upon, being a three-phaser, on the A. C. side, to maintain, first, a three-phase current relation on the transmission line, by working back through its transformers, and second, a two-phase relation on the feeder bus-bars by current working back through the Scott three-phase-two-phase transformers. It was also evident that any source of three-phase current supply would keep the rotary converter running and do the same thing, but the interesting question was, could the rotary converter be used without such source of extraneous current to keep it running, and could it then maintain the desired phase relations? In other words, could two single-phase alternators be maintained in two-phase relation by means of a rotary converter, when they were the sole source of the energy conveyed to the entire system. After careful consideration of all the reactions involved, the writer came to the conclusion that this could be done, and the experiment was decided upon. The results completely justified the confidence with which the experiment was tried. The diagram (Fig. 1) shows the conditions attending the experiment.

The generators A A having been connected with the transformers and excited so as to give the full line voltage on the transmission line C, the rotary converter E was then started in the regular way. This having been done, two of the single-phase alternators were coupled in succession to the feeder bus-bars, one to each phase. In coupling each alternator, a Lincoln synchronizer, suitably connected (not shown in the diagram), was used as a phase indicating device. After the two alternators had been coupled, each to one phase, the connections of the Lincoln synchronizer were changed so as to show the relation between the two phases of the lighting feeder bus-bars. The instrument showed that a perfect quarter-phase reiation was being maintained between the two phases, as was expected. The load on each machine could be adjusted, both by regulating the steam supplied to the engine at the throttle-valve, and by changing the excitation of the magnetic field.

After all adjustments had been completed, the line switches s were then quickly pulled open, thereby disconnecting the transmission line, and shutting off all electric energy supplied from the water power station. At the instant of disconnecting, the speed of the rotary converter fell off slightly, as was evident not only by the frequency pitch or tone, but also by the readings of the D. C. and A. C. voltmeters. This falling off was ascribed to the fact that the engine throttle-valves were not fully open. On opening the throttle, the speed rose gradually, until the frequency again became about the same as it was before disconnecting the transmission line. The index of the Lincoln synchronizer remained all the time at a point 90° from the position of synchronism, showing that the two single-phase alternators were being kept as perfectly in the same two-phase relation as when the rotary converter was run with current supplied from the transmission line. The external load was then varied by opening and closing the feeder line switches at the lighting switchboard. The maximum load put on was equivalent to more than three-quarters of the full current capacity of each alternator; the load being composed almost entirely of incandescent lights; the power factor was, of course, somewhat high.

After continuing the experiment for about ten minutes, the A, C. switches, T, of the rotary converter were opened. Mr. Beldon, who was in charge of the apparatus at the steam generating station, thereupon immediately disconnected the alternators from the feeder bus-bar lines, the synchronizer having shown that the quarter-phase relation was lost at the same instant that the rotary converter was disconnected. The experiment was repeated with slight variations two or three times, and each time with perfect success. It was found that by opening the engine throttles somewhat more than was done in the first experiment, and increasing the steam pressure available at the engine cylinder before disconnecting the transmission line, there was less falling off of the frequency at the instant of disconnecting. It was observed that the alternating current in the rotary converter increased slightly, as was expected at the time of disconnecting the transmission line. This was, of course, due to the new inter-reactions taking place between the single-phase alternators and the rotary converter in consequence of the new function imposed upon the converter, that of acting as an electromagnetic coupling and fly wheel for the two single-phase alternators. It was found that the amount of this current could be varied, to some extent, as was to be expected, by varying the field strength of the rotary converter. There were no facilities for imposing a direct current load on the rotary converter in addition to the load resulting from its operation as a phasing device for the two alternators. There is no reason to doubt, however, that a direct current load could have been placed upon the rotary converter up to the full generating capacity of the two single-phase alternators serving as the source of current supply in the experiment.

The experiment may, therefore, be taken to be a sufficient demonstration of the possibility of using single-phase alternators to produce two-phase current, three-phase current and direct current, with an arrangement and under conditions such as are shown in the diagram.

The reactions which take place between the rotary converter and the single-phase alternators, through the intermediary agency of the two sets of transformers, are quite difficult to follow and to analyze, but the writer believes that the principle on which these reactions depend is really not difficult to grasp. After the transmission line is disconnected, the entire supply of energy appearing in the system, including that necessary to drive the rotary converter must, of course, come from the two single-phase alternators, because the two steam engines driving them are now the only prime movers. The correcting force which keeps the two single-phase alternators in the two-phase relation must, therefore, be produced by a transfer of energy between the rotary converter and the alternators. It may be that what actually takes place is a transfer of energy between the two alternators themselves, or between the two A. C. phases to which they are connected, or to put it differently, the two alternators maintain their phase relation by a transfer of energy from one phase to the other through the rotary converter acting as an electro-magnetic elastic coupling.

In order to simplify the reasoning, we may assume that the rotary converter is also of the two-phase type, and that both sets of transformers, B B B and F F in the diagram, are modified accordingly. If the rotary converter were of the two-phase type, then we might consider each of the A. C. phases as a single-phase synchronous motor connected with a single-phase alternator. The rotary converter would, of course, when once started, keep in step with the alternator furnishing it with current. If, now, we were to connect another single-phase alternator on the other A. C. phase, the effect would be that any variation in the speed of one alternator would immediately react upon the other, through a sort of flywheel action of the rotary converter. The particular alternator whose frequency is increasing, owing to rise of speed, would have its load increased by an amount corresponding to the extra energy sent through the corresponding phase to the rotary converter. This energy would cause the rotary converter to accelerate. The moment the rotary begins to accelerate, it would literally " unload " the other phase, that is to say, the alternator on the other phase would have its load reduced by reason of its phase-lag behind the rotary converter. If the lag were sufficiently great, not only would the load be reduced to zero, but a " motor " current impulse would be sent from that phase of the rotary converter to the corresponding alternator, causing it to " speed up " and regain synchronism.

The synchronizing force, it is seen, comes from the phase connected with the leading alternator, to the phase connected with the lagging one. This, the writer believes, is the key to the explanation. In this particular case, there is a complication by reason of the fact that the rotary converter had three phases on the A. C. side, while the alternators were only two in number and were connected to a two-phase current system. But it will be readily seen from the diagram that there was a transmutation of phases by means of the two sets of transformers D D D and F F, through which the transfer of energy was made between the single-phase alternators and the rotary converter. The effect was substantially the same as if a two-phase rotary converter had been used. The only difference is that any disturbance in the frequency or any lead or lag in one A. C. phase, occasions cross currents which react on two of the phases on the A. C. side of the rotary converter, instead of one; and, reciprocally, any correcting current sent from the rotary converter to one of the alternators, either to increase its speed or to check it, will be sent partly over two phases instead of one.

The rotary converter, it is seen, is the coupling medium between the two alternators. It is in one sense an elastic coupling, since its operation depends on the cross currents due to slight differences of phase between the alternators and the corresponding A. C. phase of the rotary converter. It does, therefore, permit some variation in phase relation, just as would an elastic coupling. The elasticity of the coupling depends upon the amount of lag which must occur in order to cause the cross currents necessary to correct and remove this lag and restore phase synchronism between the alternator and the corresponding phase of the rotary converter. The extent to which this lag or lead will occur, that is to say, the amount of de-phasing taking place between the A. C. phase of the rotary converter and the alternator connected with the said phase, will probably vary considerably in individual cases, according to the conditions. It is not unlikely that the frequency may have considerable influence on this amount, because the frequency determines the number of times per second that the correcting influence of the alternator can be exerted. The frequency being 60 cycles, the rotary converter can, by means of cross currents, exert a correcting influence sixty times per second on each phase, and, consequently, on each alternator, and the engine driving the same. Now, the engine itself can change its mean speed, r.p.m., only by varying the amount or the pressure of the steam which it admits into the cylinder at each half stroke. In this case the engines used were of the high-speed type, running somewhere between 230 and 260 r.p.m., one having a somewhat higher speed than the other. Assuming a speed of say 240 r.p.m., we have twice that number of steam admissions, or, say, 480 per minute, which is equivalent to 8 per second. With an engine speed of 300 r.p.m., for instance, there would be ten steam admissions per second. Even supposing each steam admission to be such, by reason of change of cut-off or steam pressure, that the engine speed would tend to vary so as to change the frequency of the alternator driven by the engine, there would be only eight such disturbing reactions per second, whereas with the frequency of 60 cycles used, there could be, as already seen, 60 speed-correcting reactions per second, or seven and a half times as many. Practically, the steam admissions do not all tend to change the frequency, so as to throw out of phase the alternator driven by the engine. In most engines there is a very slight "hunting" action, whereby the steam cut-off varies slightly, first above, then below, the precise point which would maintain the speed absolutely constant. This is due to the fact that the engine governor usually varies the cut-off too much when it operates, first making it too long, then too short. The correcting effect of the cross currents is such as to restrict this oscillation within narrow limits, and to increase the number of admissions which are just right, or so nearly so as to cause but little reaction. Of course in each case the disturbing effect, due to the variations in steam admission is increased and complicated by the disturbing effects inherent in the engine, namely, the variations in angular velocity due to inertia of reciprocating parts, and to variations in the pressure applied to the crank-pin at different parts of the revolution. These, however, are of the same relative periodicity as the steam admissions, and, like them, they cause slight fluctuations above and below the mean speed. These fluctuations become minimized by the flywheel action of the rotary converters, for when they represent a slight increase in angular velocity, they cause reaction, which tends either to increase the speed of the rotary converter, or to lighten its load, or both; whereas, when they represent a decrease in angular velocity, they have the contrary effect. These reactions are explained exactly as before by the circumstance that each alternator bears a relation to the rotary converter which is exactly the same as if a single-phase alternator were connected with a single-phase synchronous motor. The alternator itself may become a synchronous motor in case, for any reason, its phase should lag behind that of the synchronous motor, or, in this case, the rotary converter. When the number of correcting impulses per second is great in comparison with the number of disturbing impulses, one would naturally expect that the range of lag or the amount of de-phasing would be smaller. This question could only be determined definitely by comparative experiments made on circuits of high and of low frequency, and by making careful quantitative measurements in each case.

Discussion.

Mr Mailloux's Paper on Single-Phase Alternators.

President Steinmetz: Gentlemen: You have listened to a very interesting paper by Mr. Mailloux concerning some interesting experiments made by him in connection with the application and use of single-phase alternators, as I might say, to help out the polyphase system. Not only to help out the polyphase system, but also to help out the polyphase system when it is not there, that is, to produce it.

Mr. Potter:—I believe the author said the single-phase alternators were first synchronized with the three-phase current.

Mr. Mailloux:—Yes.

Mr. Potter:—Would it not be possible to start the system by the steam station only, by synchronizing the two single-phase alternators in quarter-phase relation, instead of synchronizing by the three-phase from the water power station, which I understand was done in the experiment referred to.

Mr. Mailloux:—There is no difficulty in bringing the alternators into quarter-phase relation. The difficulty in following Mr. Potter's plan, is to *keep* the alternators in quarter-phase relation long enough to get the rotary converter started. The experiment might succeed and is worth trying if the hypothesis which I state is correct, namely, that we have a case where each single-phase alternator is really coupled with one corresponding phase of the rotary converter acting as a synchronous motor, then it would readily be seen that it makes no difference whether both phases are started. If we could start the rotary converter and run it at any speed at which it would excite itself, then the moment that it excited itself, we could couple one of the alternators in synchronism with it, by reducing the speed of the alternator to the correct frequency. When that has been done we could speed up the first engine, and of course the rotary converter, acting as a single-phase synchronous motor, would follow it until the proper speed desired is attained. At that time the second alternator could be coupled with it, or it could, in fact, be connected with it at a lower frequency, and then by opening the throttles of the two engines we could raise the speed to any point desired; if the hypothesis advanced is a correct one, it would seem possible to be able to start the outfit without the assistance of the line current. In the experiments tried, the line current was always used first to start the rotary converter, because that was the easiest way of doing it. We had no other means of starting the rotary converter there. You can readily understand that the arc light machines belted from it could not be used to run the rotary converter and get it up to speed. We could only do it by starting the water power station and getting a certain amount of potential on the line, which we usually raised to the full potential, and after the rotary converter was started. there of course would be no difficulty whatever.

In the paper, I make the statement that the rotary converter acts as an electromagnetic elastic coupling. The word elastic is intended to allude to the fact, which is well understood, that no correction can take place unless there is a slight change in frequency, because, if the phase relations were maintained absolutely perfect, there would be no possibility of any cross-current or synchronizing current between any phase of the alternating current and the corresponding single-phase alternator; we therefore conclude that there is a slight change or variation of frequency; and I believe if we had proper means of sufficiently accurate measurement of angular velocities, it would be clearly shown that there is a slight change of frequency and variation back and forth in the frequency. That is what is intended by the term elastic. It is the same thing as if we had a coupling which is somewhat yielding and which allows of a certain amount of motion between the two; and my reference to the effect of the difference in frequency was intended to advert to the possibility that the amount of angular variation, that is to say the *range* of elasticity in the electromagnetic coupling, would probably be, to some extent, a function of the frequency.

MR. H. E. HEATH:—In regard to this experiment, which of course is very interesting, I notice that the rotary has a direct current, and it would be quite possible to excite its field from an outside source. If that were done, and the alternator before starting was properly connected, would it not be possible to start the engines together and make the rotary pick up as the engine started?

MR. MAILLOUX:—I believe that it would, and you will find it stated in the paper that the plant will eventually include a storage battery. When that is installed, which unfortunately was not the case at the time of the experiment, it would be possible not only to excite the rotary transformer from the storage battery—that would be in fact the normal way in which it would be done—but it will also be possible to put it in motion. Under those conditions the storage battery current would be used not only as a means of keeping the rotary converter in motion, but it would also act as a " buffer " or as " ballast " capable of taking care of any fluctuations occurring between the two phases. If we had had the storage battery we would not have hesitated in using the system practically, because we would not only have a motor effect transferred from one phase to the other, namely, from the phase which is increasing in frequency to that which is lagging, but we might also have a motor effect due to current taken out of the storage battery and tending to speed up the rotary transformer, thereby supplementing the correcting effect taking place between the two alternators considered by themselves. The addition of a storage battery will greatly add to the elasticity and the value of this method. I feel so well satisfied with the practical results that I would not hesitate at all under like condition to use a method of operation of that kind.

President Steinmetz then illustrated on the blackboard an experiment made by himself some years ago.

MR. JOHN MURPHY:—Mr. Mailloux's diagram (Fig. 1) would represent exactly the conditions existing at Ottawa if a two-phase rotary converter and two-phase generators were substituted for the three-phase machines, and, if a 2,200-volt four-wire line were drawn instead of the 25,000-volt line. On many occasions we have run the two-phase rotary from one of our single-phase generators, starting it up by direct current from our storage battery, synchronizing it and throwing it onto one of our single-phase machines. Every evening we operate a single-phase generator in parallel with one phase of our two-phase machines. We have a large incandescent lighting load and we transfer some circuits from one phase to the other in order to load up the single-phase generator during peak hours. I intended to try the experiment which Mr. Mailloux has shown can be successfully carried out, because the single-phase generator works so nicely in parallel with the two-phase generators, and the rotary converter ran so well as a single-phaser that I felt certain the second single-phase generator could be connected with the other phase of the rotary converter all right. I am delighted to hear that it has been successfully done.

MR. MAILLOUX:—I consider the experiments related by Mr. Murphy to be a very satisfactory confirmation of the hypothesis which I advanced here to explain the operation under those conditions. As stated in the paper, when there is a change in phases between the machines, such as occurred in this case, the only complication that is introduced is that the energy for correcting the phase relation, instead of being sent on one phase only, is sent partly over two phases; in other words, if one of the single-phase alternators tends to get out of step with the other single-phase alternator, the corrected impulse which it sends to or receives from the electromagnetic coupling or the rotary converter, will be sent as a single-phase impulse as far as the Scott transformer, but at that point it would divide in certain proportions so as to be sent beyond that point, partly through two of the phases of the three-phase system; so, really, the apparent complication introduced in this case by the change in phases from two-phase to three-phase does not affect the theory nor the operation. The problem remains still quite as simple as it would be if we were dealing with a two-phase rotary converter and two single-phase alternators, or with a three-phase rotary transformer and three single-phase alternators.

PRESIDENT STEINMETZ:—If there is no further discussion on Mr. Mailloux's paper, I call upon Mr. Arnold, to abstract his paper on the " Method of Ascertaining from Dynamometer Car Records the Power Required to Operate the Mott Haven Division of the N. Y. C. & H. R. R. R. and the Relative Costs of Operation by Steam and Electricity."

[Mr. Arnold then read his paper.]

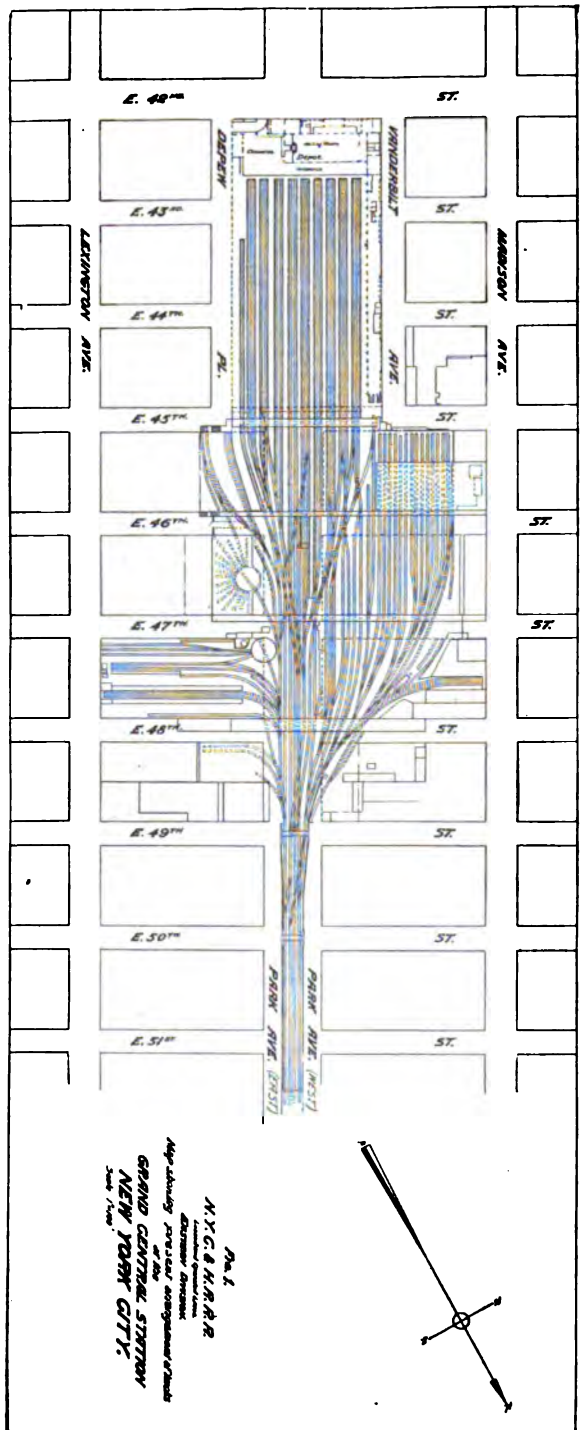
A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 19th, 1902

METHOD OF ASCERTAINING BY MEANS OF A DYNAMOMETER CAR THE POWER REQUIRED TO OPERATE THE TRAINS OF THE NEW YORK CENTRAL & HUDSON RIVER RAILROAD BETWEEN MOTT HAVEN JUNCTION AND GRAND CENTRAL STATION, AND THE RELATIVE COST OF OPERATION BY STEAM AND ELECTRICITY.

BY BION J. ARNOLD.

In August, 1901, the writer was commissioned by the New York Central Railroad Company to study the conditions governing the operation of its trains between Mott Haven Junction and Grand Central Station, and to report upon the feasibility of operating them by electricity. This division consists of 5.3 miles of four-track road forming the trunk line, or main artery over which the trains from the three divisions of the New York Central and the main line of the New York, New Haven & Hartford Railroad enter the city of New York. For 2.58 miles from Mott Haven Junction the tracks are carried on an elevated stone and steel structure; then for 2.04 miles through a tunnel underneath the street, emerging into an open cut .68 of a mile long, then terminating at the Grand Central Station in an intricate stub-end yard, having about eight miles of switching tracks. Fig. 1 shows the map of this yard. Over this division are made nearly 600 train movements per day, as nearly all trains entering the yard or station must be returned to Mott Haven Junction, owing to lack of sufficient storage tracks at the Grand Central terminus.

The annoyance to passengers due to the use of steam loco-


E. 42ND ST.
E. 43RD ST.
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E. 46TH ST.
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E. 49TH ST.
E. 50TH ST.
E. 51ST ST.
LEXINGTON AVE.
DEPEW PL.
VANDERBILT AVE.
MADISON AVE.
PARK AVE. (EAST)
PARK AVE. (WEST)
N.Y.C. & H.R.R.R.
GRAND CENTRAL STATION
NEW YORK CITY.

FIG. 1.

motives in the tunnel, caused the company to examine into the advisability of adopting electricity, and it is through the courtesy of Mr. W. J. Wilgus, chief engineer of the company under whose directions the investigation was made, that the writer is allowed to present to this INSTITUTE the technical substance of this report.

All money values relating to total cost of installation, real estate, etc., and many other elements upon which the final recommendations of the report were based, together with many of the general recommendations and conclusions themselves, are necessarily omitted from this paper, but it is believed that the data given is sufficiently complete to enable one to check the technical conclusions herein given.

Soon after taking up the work it became evident, on account of the number and weights of the trains to be handled and the numerous variable elements entering into the operating system which would not adapt themselves conveniently to formulæ, that the most practical and satisfactory way of ascertaining the power required to propel the trains was to measure, by means of a dynamometer car, the draw-bar pull of a sufficient number of trains of various weights, to determine the average power required per train and from this compute the general load diagram.

A dynamometer car known as "Test Car No. 17," owned jointly by the Illinois Central Railway Company and the University of Illinois, was obtained, and men thoroughly skilled in its use were employed to operate it. This car was coupled between the engine and the train in each case, and operated on trains running over the different divisions of the road, so that not less than four runs, two or more in each direction, were made for each class of train. Since the trains of all divisions, including those of the New York, New Haven & Hartford Railroad, run over the New York Central tracks between Mott Haven Junction and Grand Central Station, the records of the New York Central trains for this division will apply to trains of equal weights on the New York, New Haven & Hartford road, and were so considered in the calculations.

Description of Dynamometer Car:—In the dynamometer car employed, which is shown in Figs. 2 to 6 inclusive, the draw-bar is secured by means of a suitable rod to a piston head which fits closely in a cylinder filled with oil. The pull at the draw-bar thereby produces a pressure upon this oil which is transmitted

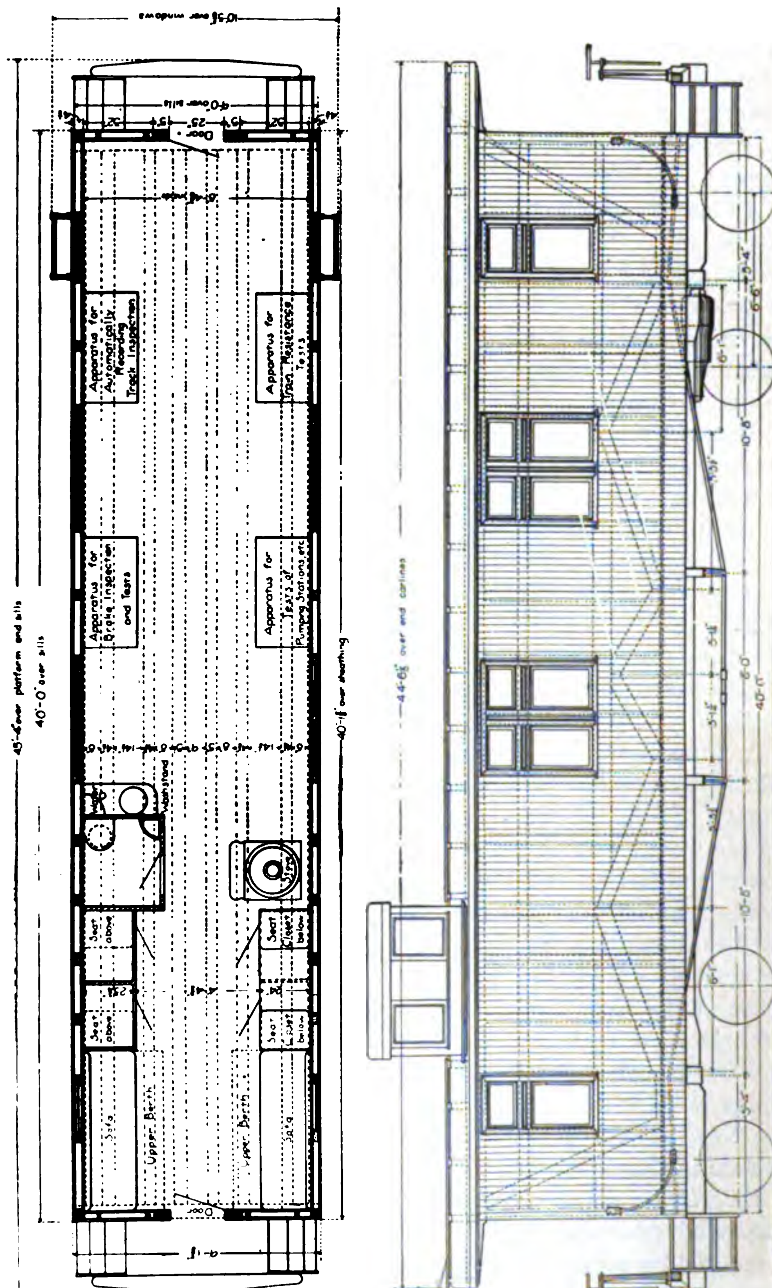


FIG. 2.

Railway Test Car of the Illinois Central R. R., and the Mechanical Engineering Department of the University of Illinois.

FIG. 3
Exterior of Dynamometer Car.

FIG. 4
Interior of Dynamometer Car.

Fig. 5
Working Table and Recording Devices of Dynamometer Car

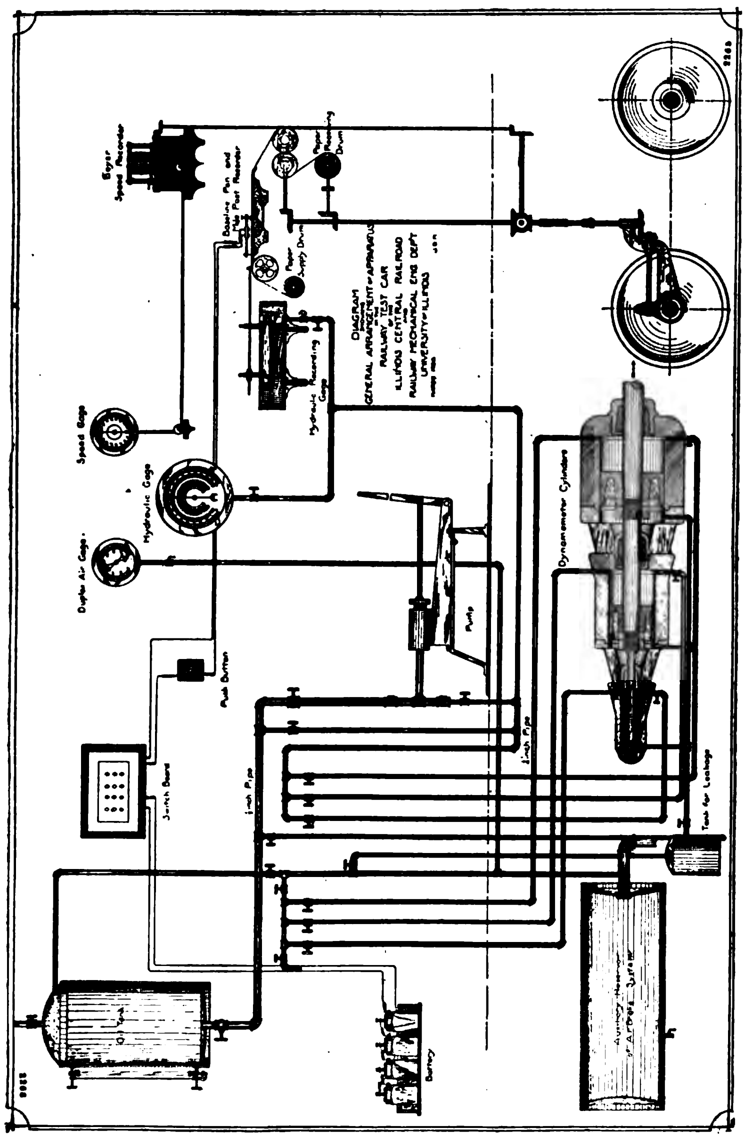


FIG. 6

Diagrammatic Arrangement of Dynamometer Car.

through suitable piping to the recording device, consisting essentially of a Bourdon gauge, which by means of a suitable arm and pen, records upon paper are driven past it by gearing from the car axle, in such a manner that the height of the record from the base line is proportionate to the draw-bar pull. This base line, and time and position lines, are produced by separate pens, the former recording every five seconds by means of clock-work, and the latter recording at mile posts, stations, etc., when an electric circuit is closed by hand. The other instruments in use on the car during these tests were a Boyer speed recorder, an anemometer for recording the relative velocity of the wind, and a weather vane showing the direction of the wind relative to the direction of travel of the car.

The dynamometer cylinders and a diagrammatic arrangement of the car are shown in Fig. 6. The cylinders are made of three castings held together by stud bolts not shown in the figure. The effective area of the largest cylinder is 60 sq. in., of the intermediate cylinder 30 sq. in., and of the smallest 5 sq. in. It is intended that the working pressure of the oil in the cylinder shall be from 300 to 1,000 lbs., per square inch, and for this range of pressure the largest cylinder has sufficient capacity for the heaviest freight service, the intermediate cylinder being used when working with a train of ordinary tonnage, and the smallest cylinder when working with a train of light tonnage. If it should become necessary, all the cylinders could be coupled up in multiple, thus giving an effective piston area of 95 sq. in.

The cylinders are reamed and the pistons and piston rods ground. The forward end of the gland is ground spherical and fits into a spherically ground seat in the stuffing box casting. This spherical seat is used to permit the three sleeves to align themselves properly on the rod. The pressure of the oil keeps the gland on its seat and this oil pressure is supplemented by the pressure of several helical springs placed between the rear end of the sleeve and the plate shown at the inner end of the stuffing box. The pistons will gradually move forward on account of leakage, but so slowly that the cylinders can be refilled from the pump at stops, or if necessary, when the cylinders are under pressure. This design was resorted to in order to avoid the uncertainty concerning the frictional resistance incident to the use of the usual packed pistons and stuffing boxes.

In Fig. 5 is shown the table upon which are placed the dynamometer recording gauge, the rolls for driving the paper chart and

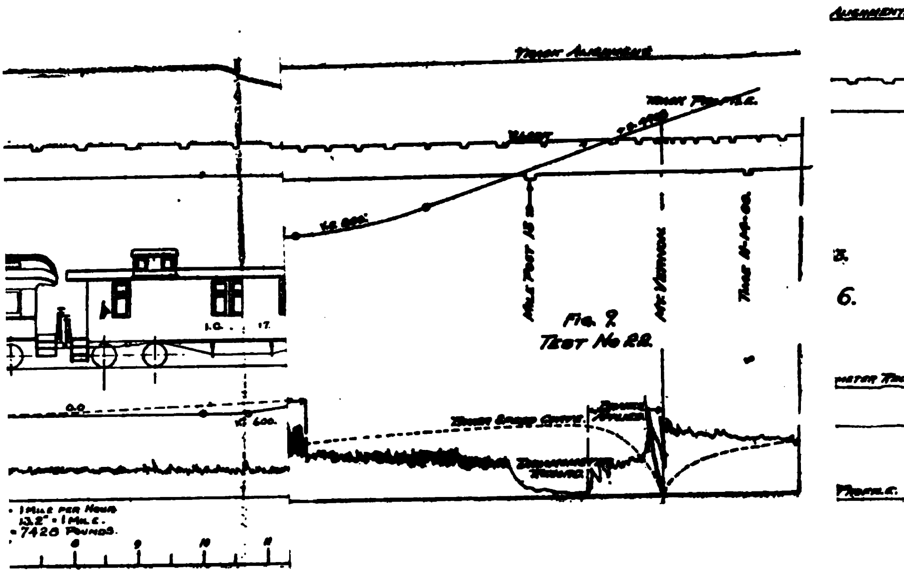
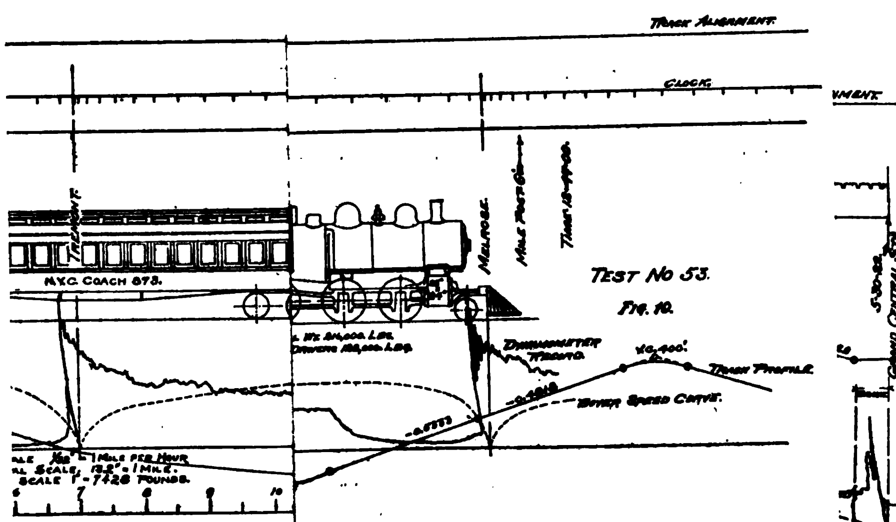


Fig. 9
Test No 22.



Test No 53.
Fig. 10.

FIG. 9.—TEST NO. 22.

Grand Central Station to White Plains, Harlem Division.
Railway Test Car No. 17, November 2d, 1901.
Passenger Train No. 111.
30 sq. in. cylinder in operation, test car forward.

Engine 1013 N. Y. C.

Weight of loaded engine	55.	tons.
Weight on drivers	38.5	"
Total weight loaded engine and tender	95.7	"

Train as follows:

17	I. C.	Test Car	44,650	lbs.
192	N. Y. C.	Combination	63,800	"
1049	"	Coach	84,340	"
840	"	"	57,900	"
			125 4	tons.
		Passengers	15.	"
Total tonnage included in record			140.4	"

Weather.—Fine, clear, temperature 61° to 68°F.
Wind very light, direction not noted.
Rail good.

FIG. 10.—TEST NO. 53.

White Plains to Grand Central Station, Harlem Division.
Railway Test Car No. 17, November 19th, 1901.
Passenger Train 130.
30 sq. in. cylinder in operation, test car forward.

Engine 1407 N. Y. C.

Total weight	108	tons.
Weight on drivers	64	"
Weight with tender	108	"

Train as follows:

17	I. C.	Test Car	44,650	lbs.
1020	N. Y. C.	Coach	65,500	"
873	"	"	60,900	"
231	"	Combination	60,300	"
2686	"	Express	54,300	"
2572	"	"	81,000	"
			183.3	tons.
		Passengers	36.6	"
Total tonnage included in record			220.0	"

Weather.—Clear and dry, temperature 48° F.
Passenger and Anemometer records taken.
Rail good.

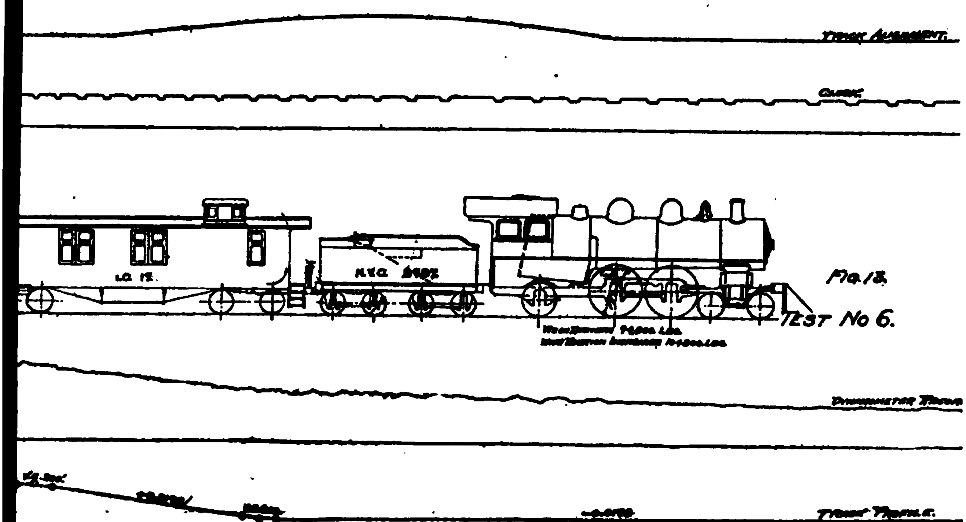

Track Alignment.
Gauge
L.C. 13.
N.Y.C.
Test No 6.
Track Profile.

Fig. 13.

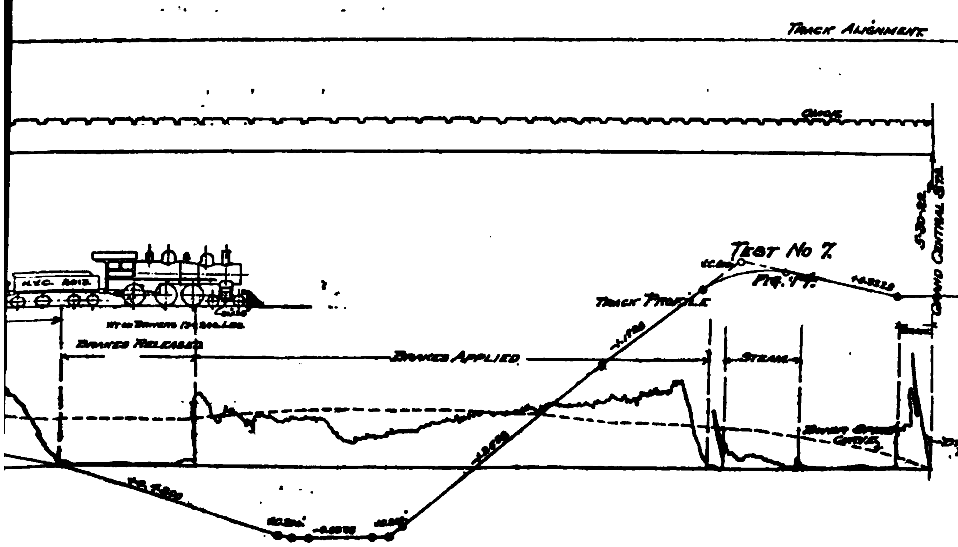

Track Alignment
Gauge
N.Y.C. 2013.
Test No 7.
Track Profile
Brakes Released
Brakes Applied
Steam
Grand Central Sta.

Fig. 14.

FIG. 13.—TEST NO. 6.

Syracuse to Albany, Mohawk Division.
Railway Test Car No. 17, Oct. 25th, 1901.
Passenger Train No. 14.
30 sq. in. cylinder in operation, test car backward.
Engine 2987 N. Y. C.

Weight of loaded engine	88.	tons.
Weight on drivers	47.4	"
Using traction increaser	52.4	"
Total weight loaded engine and tender	144.5	"

Train as follows:

17	I. C.	Test Car	———	lbs.
215	N. Y. C.	Mail	56,300	"
770	"	Baggage	60,000	"
206	"	Combination	84,000	"
932	"	Coach	87,000	"
897	"	"	58,200	"
910	"	"	87,700	"
949	"	"	94,500	"
" Seawanhaka " Pullman Drawing Room Car			89,000	"
" Godfrey " " " " "			57,300	"
			337.0	tons.
		Passengers	17.0	"
Total tonnage included in record			354.0	"

Weather.—Clear.
Rail good

FIG. 14.—TEST NO. 7.

Chicago to New York.
Railway Test Car No. 17, Hudson Division.
Passenger Train No. 28.
30 sq. in. cylinder in operation, test car running backward.
Engine 2013 N. Y. C.

Weight of loaded engine	87.6	tons.
Weight on drivers	67.15	"
Total weight loaded engine and tender	143.5	"

Train as follows

17	I. C	Test Car	———	lbs.
2739	N. Y. C.	Baggage	59,000	"
202	C. C. C. & St. L.	Express	50,000	"
2771	N. Y. C.	"	44,500	"
2656	"	Baggage	52,500	"
585	"	"	59,100	"
2106	"	Mail	86,000	"
2114	"	"	80,100	"
1980	"	Coach	70,000	"
966	"	"	94,800	"
928	"	"	67,900	"
" Navarin " Pullman Sleeper			108,000	"
" Shenango " " "			97,000	"
			434.45	"
		Passengers	21.72	"
Total tonnage included in record			456.17	

Weather.—Clear and cool, wind light, direction not noted.
Rail condition good

the Boyer speed recorder. The vertical shaft projecting through the floor under the middle of the table, derives its motion from the car axle by means of worm and bevel gears. Its motion is transmitted by means of the gears shown, to the speed recorder and the paper driving apparatus. This consists of a pair of driving rolls, around which the paper passes, and supply and receiving rolls. The paper is drawn from the formei and fed to the latter after running over the drum of the recorder.

Discussion of Dynamometer Records.

Figs. 7 to 14 inclusive show the dynamometer car records of eight different classes of trains which are in daily operation over some of the divisions of the road. On each record is shown graphically the following:

(1) The " draw-bar pull " of train shown in the irregular heavy line as recorded by the pen of the dynamometer cylinder, each inch of height from the base line being equivalent to 7,428 pounds of draw-bar pull exerted by the engine on the train, which is shown in outline on the record, the horizontal scale being 13.2 inches to the mile.

(2) The speed of the train is shown by the regular dotted line, each thirty-second of an inch of height representing a speed of one mile per hour.

(3) The profile of the road is shown at the bottom and the alignment at the top of each record, so that it is possible to calculate by formulæ the theoretical horse power required to haul the train under the conditions of each case and after equating for grade and curvature, check the result by the curves here given.

It should be noted that the records do not include the power required to propel the locomotive, nor the head-end resistance offered to it by the air, and that when the dynamometer car was running backward, the power to propel it is not represented in the record and its weight should not be taken into consideration as a part of the train. These factors were taken into account when determining the final load diagram.

The diagrams are arranged in the order of the train weights with the light trains first, and a few trains have been introduced which do not operate over the particular division under consideration.

Fig. 7 represents a light suburban train running on the New York & Putnam Division from Putnam Junction to 155th Street.

Fig. 8 represents a light suburban train of the Harlem Division which runs between Grand Central Station and Lake Mahopac.

Fig. 9 represents a suburban train which runs on the Harlem Division between Grand Central Station and White Plains.

Fig. 10 shows a moderate weight suburban train of the Harlem Division which runs between White Plains and Grand Central Station.

Fig. 11 represents a standard local through train on the Hudson Division known as the Day Express, stopping at practically all stations.

Fig. 12 represents a through local train known as the Day Express, which stops at nearly all stations.

Fig. 13 represents a through fast train running between Buffalo and Albany, known as the New York & New England Express, which makes the fastest through time between Chicago and New York and Boston made by any train on the road.[1] This record is introduced as an interesting example of the requirements of heavy through train service and as a part of the record taken on a through run from Chicago to New York, a distance of nearly one thousand miles.

The train was hauled by the latest type of New York Central passenger locomotive, which has hauled a train of sixteen cars, weighing with the locomotive over 900 tons, at a speed of 60 miles per hour, and maintained the schedule speed of over 45 miles per hour with the same train between New York and Albany.

On the run from which Fig. 13 was taken, the engine maintained for a considerable distance a speed of 63 miles per hour, with 10 cars, constituting with the engine a train weighing 494 tons, thus developing continuously 940 h.p., assuming the ordinary allowance for head-end resistance due to wind or air pressure. At another time and with a heavier train, this engine developed 1,452 i.h.p., at 63 miles per hour, 240 r.p.m., as shown by indicator cards.

Fig. 14 represents the record from Mott Haven Junction to Grand Central Station of a through heavy express train known as the New York & Boston Express, loaded heavily with express matter, mail and papers, but carrying few passengers.

It is thought that the records here introduced are sufficient in number and character to represent fairly well the various classes of duty required of the present steam locomotives, and what would be required from electric locomotives in case they should be adopted, as the problem submitted was to duplicate

1. Since writing this, the new 20-hour train known as the "Twentieth Century Limited" between New York and Chicago has been put in service.

the present passenger train service between Mott Haven Junction and Grand Central Station, by using electric power instead of steam locomotives.

The questions of changes in the Grand Central terminal, or of the present method of train operation, or of handling the suburban trains on the division outside of Mott Haven Junction are not considered in this paper.

It appears that the braking effort per ton is not as high on certain types of locomotives as it is on coaches. This is due to the fact that not all the wheels of the locomotive are always braked, and those that are braked cannot be set to the skidding point with a fully loaded tender, for if they were they would then skid with a lightly loaded tender. Hence the draw-bar pull during retardation is often as great, or even greater than it is during acceleration. An instance of this is seen in Fig. 12 at (*b*), where the maximum draw-bar pull due to the braking effort of the train on the locomotive is 11,950 lbs., while the maximum draw-bar pull exerted in starting the trai[illegible]) is 9,945 lbs. That is to say, in this particular run during the period over which all possible retardation is desired, the draw-bar pull instead of being zero, is 20% greater than that available for acceleration. In Fig. 9, for the stop at Wakefield these figures become respectively 15,675 lbs., 9,899 lbs. and 60%. At all other stops on this record it is seen that the braking effort of the train is nearly equal to the maximum starting effort of the locomotive during acceleration.

The severe oscillation of the dynamometer pen on this record exhibits the irregular turning moment of the engine which is caused partly by unequal distribution of the steam in the cylinders, due to the lack of proper adjustment of the valve motion, and partly to the irregular turning moment of any two-cylinder engine of this type.

In Fig, 10, however, which is the record obtained from engine No. 1407—one of the latest type of suburban engines on this road—the smoothness of the record, and the perfect braking of the engine and train are noticeable.

Where these records are marked "pump," the dynamometer cylinder was being filled with oil from the hand pump provided for this purpose.

The various phases in the cycle of locomotive performance are clearly seen in the dynamometer records; thus, in Fig. 11, at (*b*) the engine was given steam, at (*c*) hooked up, and at (*d*) given more steam, at (*e*) again hooked up, and at (*f*) again given more steam; at A^{VI} steam was cut off and the train coasted to (*g*) where brakes were applied, released, and again applied at (*h*), etc., etc.

Method of Obtaining Horse Power at Draw-Bar from Dynamometer Records.

This was obtained in general in the following manner: From

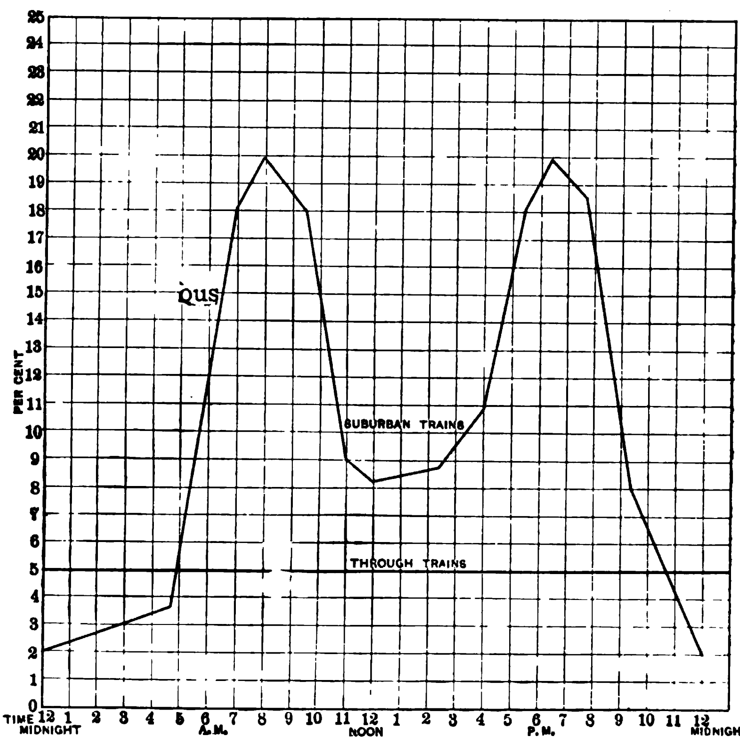


FIG. 15
Percentage of Passenger weight to Light Train weights, Grand Central Station to Mott Haven Junction.

actual dynamometer car tests the average draw-bar pull of the various trains over the various runs was determined, proper allowance made for increased train weight due to motor equipment, and finally a reduction of the draw-bar pull thus obtained to horse-power, and eventually to kilowatts. Owing to the fact that the maximum speeds on this division seldom exceed 35 miles per hour and that the trains were never less than three

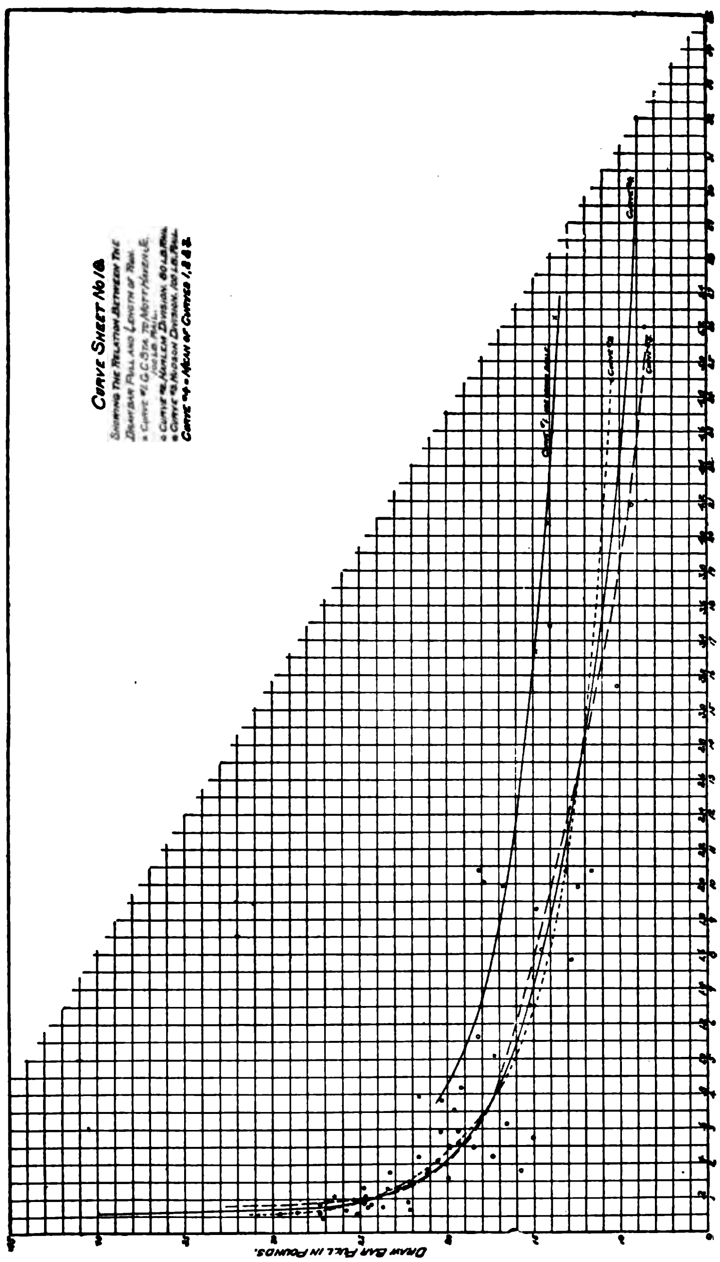

CURVE SHEET No 16
LENGTH OF RUN IN MILES.
DRAW BAR PULL IN POUNDS.

FIG. 16.

cars in length—often reaching eleven cars in length—no correction was made for head-end air resistance.

The successive steps were as follows:

(1) In order to determine the average draw-bar pull for any given period, the entire area under the dynamometer pen record was found by a planimeter and divided by the length of base of the interval from start to stop, the result being the average draw-bar pull. Thus, in Figs. 7 to 14 inclusive, which are characteristic dynamometer records, the areas A′, A″, etc., were found by a planimeter; by dividing any area thus found by the total length of its base between stops, the average height of the dynamometer records between stops is obtained. This average height when multiplied by the constant of the instrument, represents the average draw-bar pull between these stops.

(2) From passenger records taken during dynamometer tests, the curve shown in Fig. 15 was plotted, showing the ratio of the weight of the live load to the light weight of the train.

(3) Dividing the average pull in pounds by the total weight of the train, the average pounds per ton draw-bar pull over the run under consideration, was obtained. The average pounds per ton draw-bar pull thus obtained for each run is shown in Table I, page 637. The means of the values set forth in Table I are shown in Table II, page 638.

The average pounds per ton draw-bar pull (not tractive effort) for various lengths of run over the Mott Haven Division are shown in Curve 1, of Fig. 16. Curves 2 and 3 show these values for longer runs, as obtained on the Harlem and Hudson Divisions respectively, and Curve 4, which is the mean of Curves 1, 2 and 3, shows very roughly what may be expected to obtain as the average value of the "pounds per ton" draw-bar pull under ordinary steam railroad conditions, on a level and comparatively straight track, with various weights and lengths of train (three to ten cars, 100 to 400 tons), and at an average speed of about thirty miles per hour.

The question of grade is here eliminated, for each point shown represents the average value of two runs on the same train, one North, the other South.

The number of variables entering into these values such, for example, as the degree of skill of the engineer, the wind velocity, the condition of the track, agreement with schedule time, etc., make it impossible for any curve to pass through all its points and therefore, as above stated, these curves can only be taken as

TABLE I.

AVERAGE DRAW-BAR PULL, IN POUNDS PER TON, FOR DIFFERENT RUNS ON N. Y. C. AND H. R. R. R.

Division Key H., Hudson. A., Harlem.

						Between							
						G. C. Station and 110 St.	110 St. and 125 St.	G. C. Station and 125 St.	125 St. and 138 St.	G. C. S. and 138 St.	138 St and Jct.	G. C. S. and Jct.	Jct. and 125 St.
Run.	† Out. In +	Train.	Division.	Tons.	Pounds.	3 42 M.	0.96 M.	4.38 M.	0.57 M.	4.95 M.	0.85 M.	5.3 M.	.93 M.
19	+	120	H.	167.3	4180				25.0				
"		"	"	"	2480			14.8					
22	†	111	H.	136 5	3080		22.3						
"		"	"	"	2240				16.4				
		"	"	"	3620						26.5		
13	+	116	H.	126.4	1840						14.55		
"		"	"	"	2820				22.18				
"		"	"	"	1800			14.75					
18	†	113	H.	121.5	4000						32.9		
"		"	"	"	2800				22.1				
"		"	"	"	1840			15.12					
52	†	115	H.	108 6	2180	20.05							
"		"	"	"	2880		26.5						
"		"	"	"	2820				25.9				
"		"	"	"	3280						30.2		
53	+	130	H.	193 1	4385						22.6		
"		"	"	"	4800				24.8				
"		"	"	"	5240		27.1						
"		"	"	"	2430	12.6							
55	+	153	H.	125.8	920						7.3		
"		"	"	"	3360				26.7				
"		"	"	"	3280		26.						
"		"	"	"	1640	13.01							
12	†	111	H.	124.0	2300	18.6							
"		"	"	"	2780		22.4						
"		"	"	"	2600				21.0				
"		"	"	"	4020						32.4		
23	+	116	A.	138.5									
"		"	"	"	3140				22.7				
"		"	"	"	1540			11.11					
49	+	28	A.	95									
"		"	"	"	2840				24.7				
"		"	"	"	1250			13.2					
41	+	88	H.	162.2	1884							11.62	
40	†	83	H.	231.3	3910			16.91					
"		"	"	"	3826				16.5				
"		"	"	"	6340						27.4		
39	+	84	H.	248.5	3500								14.2
"		"	"	"	2410			9.7					
38	†	87	H.	230.5	3015							13.03	
37	+	120	H.	117.6	2260								19.22
"		"	"	"	1488			12.21					
35	†	107	H.	143.8	2590			18 05					
"		"	"	"	3120								21.75
21	+	84	H.	267.8	4020								15.7
"		"	"	"	2925			10.92					
11	+	104	H.	223.8	3088							13.82	
16	†	108	H.	167.6	3122			18.65					
"		"	"	"	3110				18.6				
"		"	"	"	2960						17.7		
17	+	114	H.	176.1	4290								24.3
"		"	"	"	2984			16 95					
20	†	85	H.	230.	2410					10.46			
"		"	"	"	4960						21.7		
10	†	117	H.	195.	2890			14.8					
"		"	"	"	4200				21.5				
"		"	"	"	5050						25.9		
48	†	17	A.	137.3	1880	13.3							
"		"	"	"	2780		20.2						
"		"	"	"	2550				16.58				
"		"	"	"	4500						32.7		
14	†	11	A.	193.4	2560			13.25					
"		"	"	"	2835				14.65				
"		"	"	"	4425						22.85		

TABLE I.—(*Continued.*)

AVERAGE DRAW-BAR PULL, IN POUNDS PER TON, FOR DIFFERENT RUNS ON N. Y. C., AND H. R. R. R.

Division Key. H., Hudson, A., Harlem.

Run.	+ Out. † In +	Train.	Division.	Tons.	Pounds.	Between: G. C. Station and 110 St.	110 St. and 125 St.	G. C. S. and 125 St.	125 St. and 138 St	G. C. S and 138 St.	138 St. and Jct.	G. C. S. and Jct.	Jct. and 135 St.
						3.12 M.	0.96 M.	4.38 M.	0.57 M.	4.95 M.	0.85 M.	5.3 M.	92 M.
15	+	24	A.	118.0	2725				23.05				
"		"	"	"	1495			12.7					
54	†	147	A.	213.2	3420	16.0							
"		"	"	"	4450		20.9						
"		"	"	"	3700				17 85				
"		"	"	"	5100						23.9		
7	+	28	H.	425.	3500						8.25		
"		"	"	"	7440				17.25				
"		"	"	"	5510			13.0					
42	†	93	H.	316.6	3660			11.56					
"		"	"	"	5000				15.8				
"		"	"	"	6410						20.25		
43	+	70	H.	195.3	27[illegible]0								14.23
"		"	"	"	1890			9.68					
44	†	69	H.	283.4	4150			14 66					
"		"	"	"	4790				16.9				
"		"	"	"	4920						17.37		
45	+	78	H.	142.7	2820								19.72
"		"	"	"	1365			9.66					
46	†	47	H.	235 1	3075					13.06			
"		"	"	"	5680						24.21		
47	+	2	H.	307.	4785								15.6
"		"	"	"	3405			11.1					
50	†	71	H.	400.	4980			12.45					
"		"	"	"	3380								8.44
51	+	62	H.	392.1	5140								13.1
"		"	"	"	3900			9.95					
56	†	7	H	310.6	3890			12.52					
"		"	"	"	3200				10.3				
"		"	"	"	4840						15.58		

TABLE II.

SHOWING AVERAGE DRAW-BAR PULL IN POUNDS PER TON, AND HORSE-POWER REQUIRED TO PROPEL ELECTRIC LOCOMOTIVES FOR DIFFERENT RUNS.

TERMINAL STATIONS Of run.	GOING OUT.		COMING IN.	
	2	3	4	5
1	Draw bar pull per ton	Locomotive h.p.	Draw bar pull per ton	Locomotive h.p.
Between G. C. Station and 110th Street.	17 lb.	75. h.p.	12.80 lb.	71. h.p.
" " " " 125th "	16.13 "	88. "	12 10 "	65. "
" " " " 138th "	12.00 "			
" " " "Mott Haven Jc.	14.80 "	76. "	12.72 "	56. "
" 110th Street " 125th Street	22.46 "	95. "	24.00 "	98. "
" " " " 138th "				
" " " "Mott Haven Jc.			13.10 "	
" 125th " " 138th Street.	18.10 "	51. "	22.70 "	55. "
" " " "Mott Haven Jc.	16.00 "	73. "	17.00 "	58. "
" 138th " " " "	25 00 "	62. "	14.80 "	65. "

NOTE.—Figures given in columns 3 and 5 represent the average horse-power required to propel a 65 ton electric locomotive over that run, plus one horse-power for pumps.

indicating the average value of a widely varying quantity.

(4) Fig. 17 shows a graphical method of obtaining the speed in miles per hour between any two stations when the time of run between these two stations is given. If the lower strip of this diagram be cut off along the dotted line and placed horizontally at the left with any station on the ordinate at the given time, the intersection of any other station with an oblique line gives the average speed between these stations. Thus, for example,

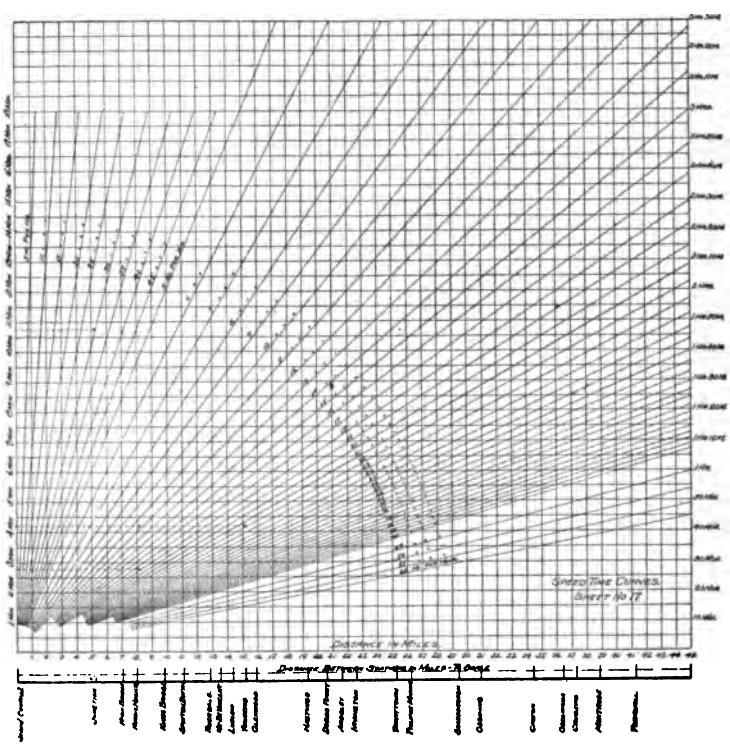


Fig. 17.

if the run from Grand Central Station to Yonkers is made in 42 minutes, by placing " Grand Central Station " on the ordinate at the left at 42 minutes and running horizontally along the strip to " Yonkers," the oblique line here intersected shows the average speed to be 22 miles per hour; in the same manner, if the run from Grand Central Station to Mott Haven Junction is made in 10½ minutes, the average speed is thirty miles per hour. Again, by placing " Spuyten Duyvil " on the ordinate at the left at 28 minutes, and following horizontally to " Hastings," the average speed between these two stations is seen to be 18 miles per hour.

(5) The weight of every train arriving or leaving the Grand Central Station on a given day was obtained, and its average speed between stops determined from the above curves. Knowing, therefore, the average draw-bar pull in pounds required to haul a train, and the average speed at which this draw-bar pull

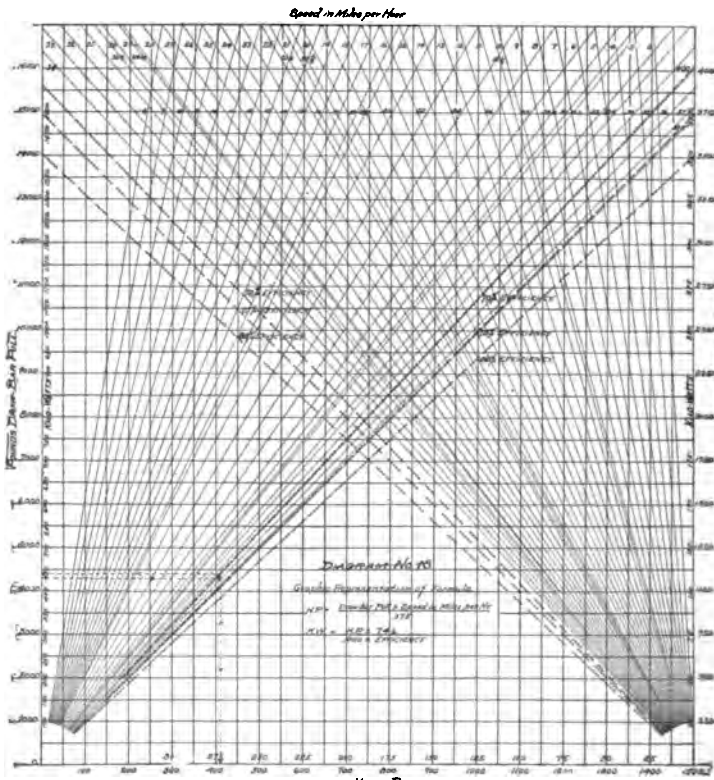


FIG. 18

was exerted, the horse power at the draw-bar becomes:

H.P. = foot pounds per minute/33,000

= draw-bar pull × miles per hour × 5,280/33,000 × 60

= draw-bar pull × miles per hour/375

This formula is represented graphically in Fig. 18, from which, knowing the draw-bar pull and speed, the horse power or kilowatts corresponding thereto is determined. Thus, for example, if the draw-bar pull is 4,300 lbs., at a speed of 36 miles per hour, to find the horse power or kilowatts corresponding thereto. At 4,300 lbs., on the ordinate at the left of the figure, follow the dotted line to the right until it intersects the required speed curve, thence downward to the base line thus obtaining 410 horse power. If the efficiency of the motor is taken at 70%, by following the ordinate at 410 horse power vertically to the 70% curve and thence to the left, the kilowatt capacity required is found to be 440 k.w., which is the power required to propel the train, exclusive of the locomotive and head-end resistance.

Now, referring to the first line of Table 3, which represents the results obtained by calculating the power required for the train service of Oct. 23, 1901, we have for the first train shown:

In Column 1, the division over which the train runs, namely "N" (N. Y., N. H. &. H.)

In Column 2, the train number.

In Column 3, light weight of train.

In Column 4, weight of train loaded, which was obtained by reference to the curve in Fig. 15, showing the weight of passengers to be added to the light train weight.

The first stop being at 125th Street, Columns 5, 6, 7 and 8 are blank, but show by daggers the direction of movement, thus ←North, → South.

In Column 9, is found the average speed obtained as above.

In Column 10, the pounds draw-bar pull from Table 2.

In Column 11, the product of "pounds per ton," times total tonnage of train

In Column 12, the average horse power required to haul a train, exclusive of the locomotive, from Grand Central Station to 125th Street; this value was obtained from Fig. 18, and is:

$$5{,}227 \times 32.8/475 = 458 \text{ horse power.}$$

No stop being made at 138th Street, Columns 13, 14, 15 and 16 are blank.

In Column 17, the average speed from 125th Street to Junction is found as above.

In Column 18, average pounds per ton draw-bar pull over this run.

In Column 19, the average total draw-bar pull.

In Column 20, the average horse power required at the draw-bar over this run.

The horse power required for each scheduled train over each run was obtained in the same manner and the results as taken from this table were plotted and are shown on train diagram sheets, Figs. 19, 20, 21 and 22.

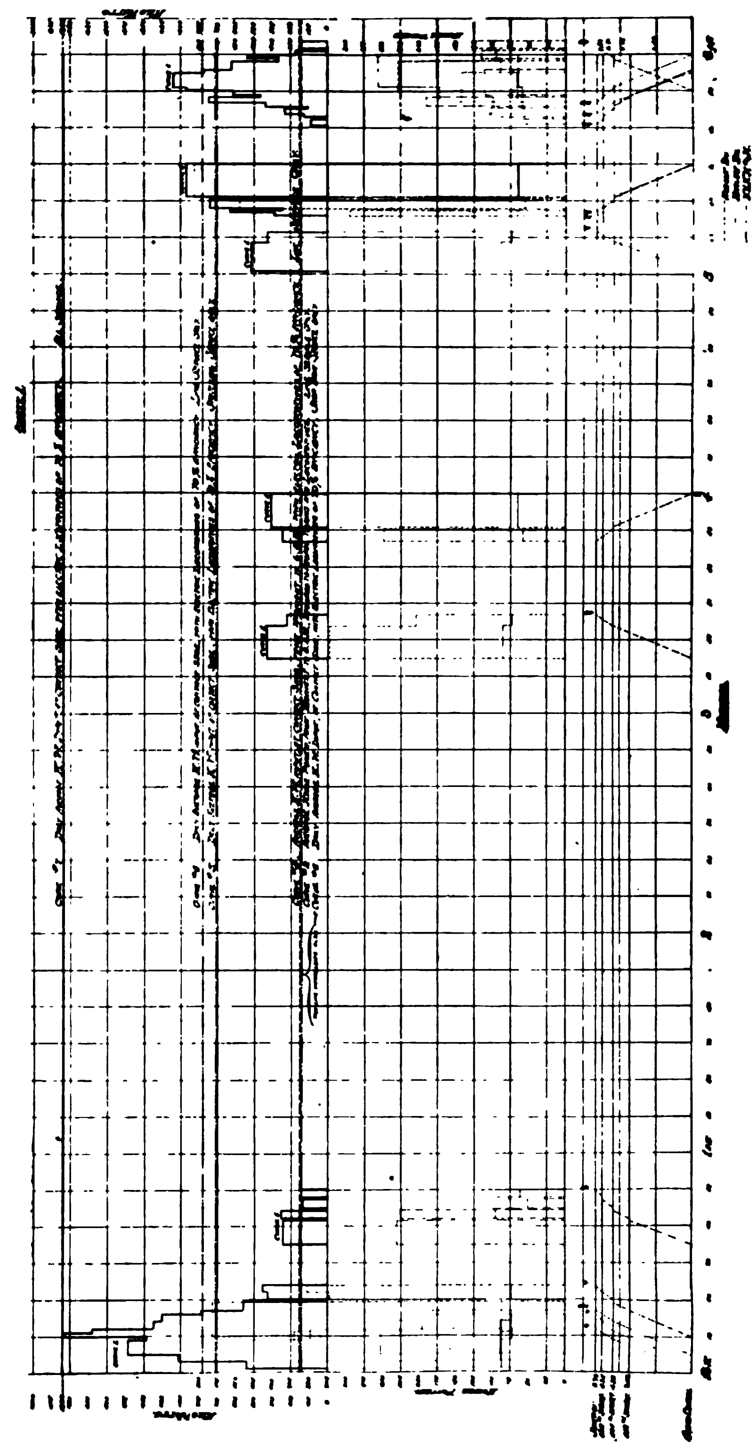


FIG. 19.—Train and Load Diagram for Oct. 2], 1901, showing energy required for proposed electric locomotive service between Grand Central Station and Mott Haven Junction frcm 12 o'clock midnight to six o'clock A. M.

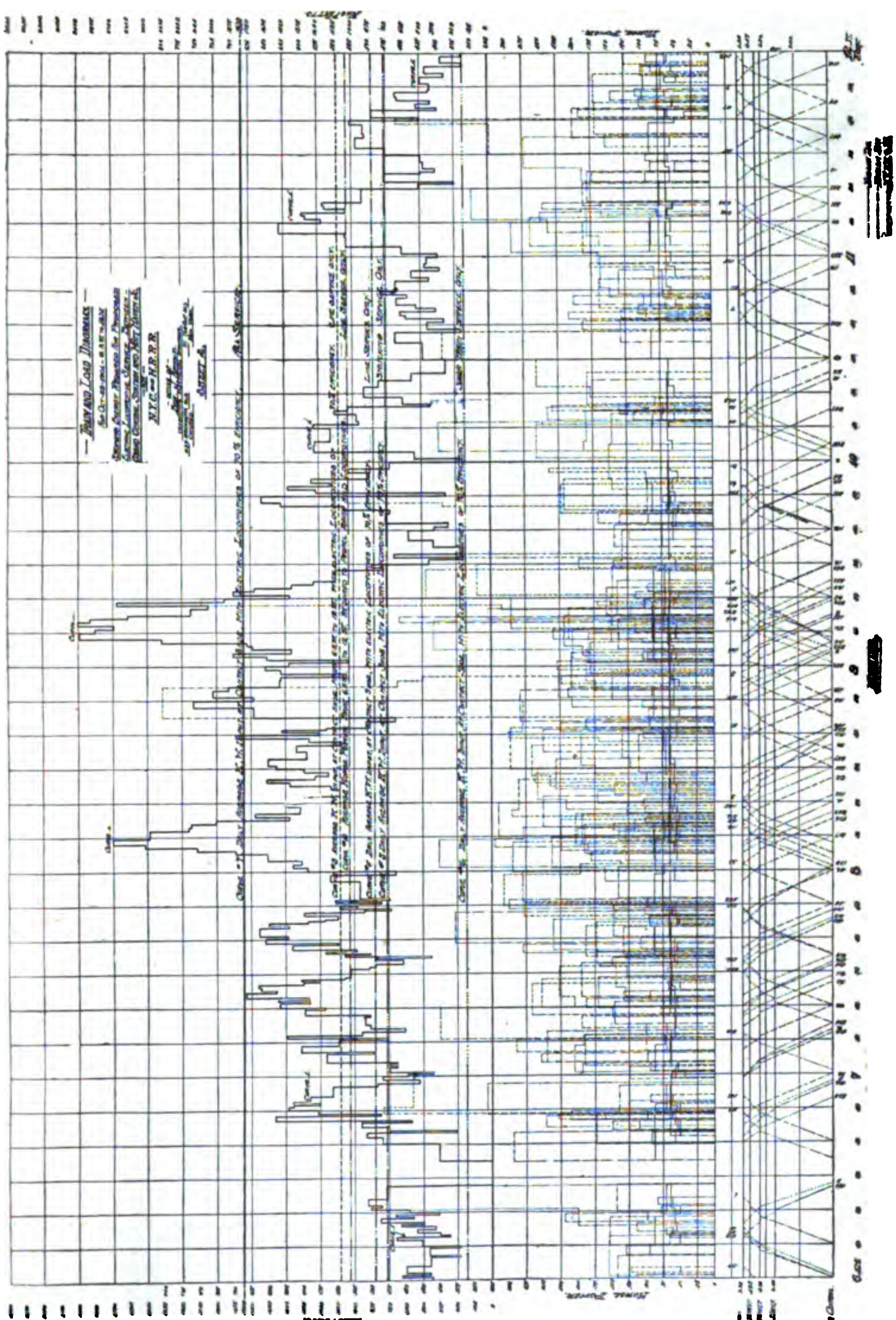


Fig. 20.—Train and Load Diagram for Oct 23, 1901, showing energy required for proposed electric locomotive service between Grand Central Station and Mott Haven Junction, from six o'clock A.M. to 12 o'clock noon.

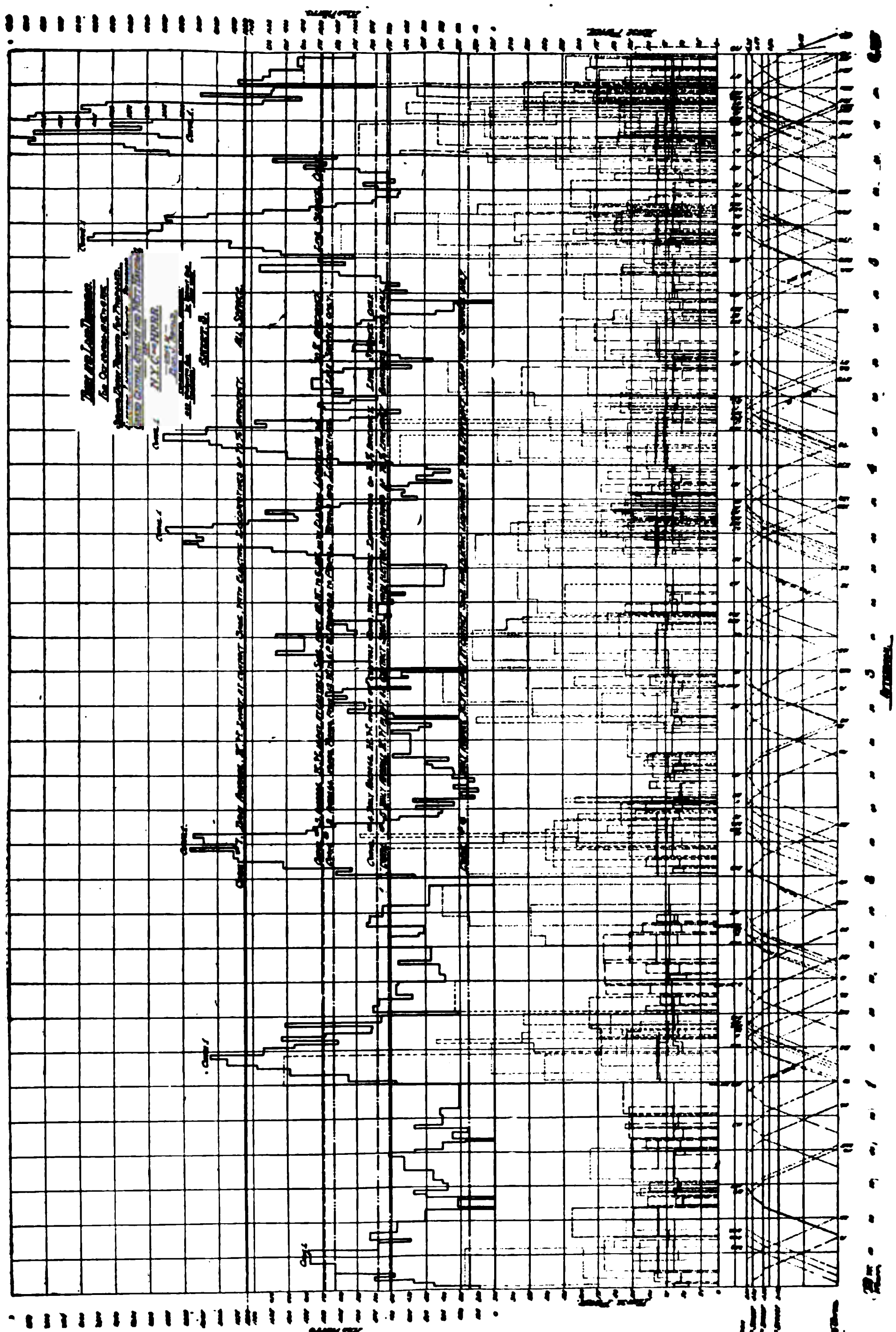


FIG. 21.—Train and Load Diagram for Oct. 23d, 1901, showing energy required for proposed electric locomotive service between Grand Central Station and Mott Haven Junction, from 12 o'clock noon to 6 P.M.

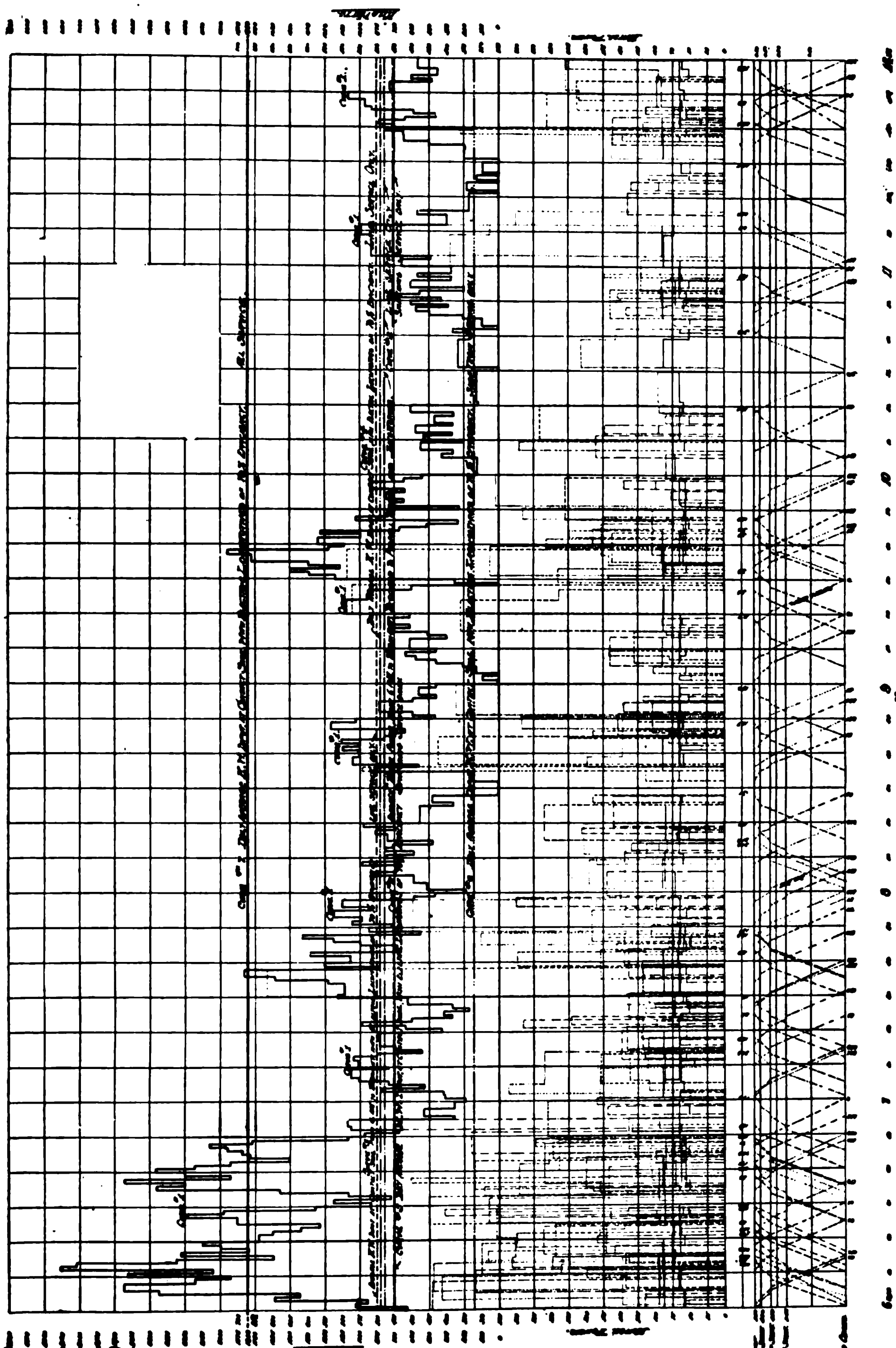


FIG. 22.—Train and Load Diagrams for Oct. 25th, 1901, showing energy required for proposed electric locomotive service between Grand Central Station and Mott Haven Junction, from 6 o'clock P.M. to 12 o'clock midnight.

Method of Obtaining Daily Load Diagram.

From a careful examination of the weights of all locomotives now in service on this division, it was found that properly powered electric locomotives having a total weight of 65 tons each, all of which would be available for tractive effort, could satisfactorily perform the service of existing steam locomotives.

To each train horse power curve, therefore, as plotted on Train Sheets, Figs. 19, 20, 21 and 22, is added the horse power required to propel a 65-ton locomotive.

This horse power was obtained in the same manner as that required to haul the train and was plotted separately on the train sheets; evidently, the friction of an electric locomotive in pounds per ton is greater than an equivalent weight of train, but this difference was considered in selecting the proper locomotive efficiency.

The sum of the instantaneous values of these individual curves was then plotted as the irregular black line Curve 1, in Figs. 19, 20, 21 and 22. The mean height of this curve is plotted as the straight line Curve 2, on each sheet, and represents the average horse power required to propel all schedule trains and locomotives during the six hours covered by the sheet.

This average horse power when converted into kilowatts by means of the following formula (which is exhibited graphically in Fig. 18):

$$\text{k.w.} = \text{h.p.} \times 746/70\% \times 1{,}000$$

where 1,000 watts = 1 k.w.
746 watts = 1 electrical h.p.
and 70% = efficiency of locomotives

gives the average kilowatt input required at contact shoes of electric locomotives for the period covered by each sheet and appears as Curve 3.

Curve 4 represents the mean average kilowatt input at contact shoes (for line service only) throughout a period of 24 hours, under the same conditions, and its height is the average height of Curve 3, in Figs, 19, 20, 21 and 22.

The switching, shop train and return engine service was found to represent such hourly demands as are shown in Curves 3 and 4 of Fig. 23.

The mean height of Curve 3 on Fig. 23, appears as Curve 5, in Figs. 19, 20, 21 and 22, and similarly, the mean height of Curve 4, on Fig. 23, appears as Curve 6, on Figs. 19, 20, 21 and 22.

The sum of Curves 4, 5, and 6 on Sheets 19, 20, 21 and 22, is plotted as Curve 7, on those sheets, and therefore represents the AVERAGE DAILY KILOWATT INPUT REQUIRED AT CONTACT SHOES OF LOCOMOTIVE FOR ALL SERVICE.

Curve 1 of Fig. 23, is a condensed load diagram of the entire service, showing the hourly variation of the different classes of service, as deduced from the curves in Figs. 19, 20, 21 and 22.

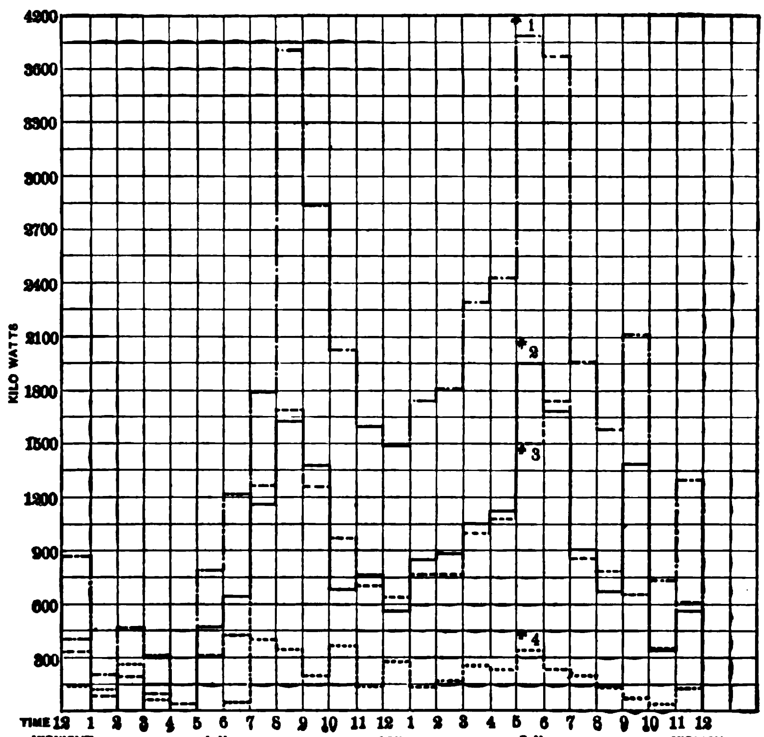


FIG. 23

From Curve 7, on these sheets, it is seen that the daily average input required would be at the rate of 1,800 kilowatts and, therefore, the total annual input required at the contact shoes of the locomotives, for propulsion alone, would be ($1,800 \times 24 \times 365$) = 15,768,000 k.w. hour). From the total number of tons hauled yearly over this division, including passenger, shop trains and switching service, the ton-miles per year were found to be 250,285,710. Hence, the electrical energy required to haul a ton one mile over this division under the existing conditions would be

FIG. 24
Locomotive Used in Test No. 27.

FIG. 25
Type of Locomotive Used in Test No. 48.

FIG. 26
Type of Locomotive Used in Test No. 22.

$$15,768,000,000/250,285,710 = 63 \text{ watt hours per ton-mile.}$$

With this figure as a basis and the load factor as determined from the load diagram, the problem of determining the best method of producing, distributing and applying the power was considered.

Choice of System.

While it is the writer's opinion that the alternating current railway motor will yet prove to be the most efficient, all things considered, for long-distance railway work, it has not yet in his opinion demonstrated its ability to start under load as efficiently or to accelerate a train as rapidly as the direct current motor. The line under immediate consideration was short, the trains numerous and rapid acceleration desirable, all of which are conditions favorable to the direct current motor.

Furthermore, direct current motors with their necessary auxiliaries have become fairly well standardized and it is the only class of electric railway apparatus available from the manufacturers of the United States without involving experimental work and large development expense.

In view of these facts and the probable necessity for rapid construction, the writer refrained from advising anything of an experimental nature and, therefore, recommended the direct current system in combination with the third rail for the main line, and overhead construction for the yards, all of which have demonstrated fully their ability to meet the conditions imposed by railway operation so far as motive power is concerned, although there has not yet been an electric installation on any existing terminal that is as complex, or into which anywhere near the number of heavy trains enter, as on this section of road.

Had the length of road under consideration been considerably greater, and had it been thought possible to secure sufficient time to conduct experiments or invite demonstrations by manufacturers of alternating current motor equipment, this class of apparatus would have been more seriously considered.

Discussions and Analysis of Plans and Estimates.

In the preparation of estimates, twelve distinct plans of generation and distribution were considered and the results tabulated as shown in Table 4. All the estimates were computed upon the same basis so far as cost of fuel, labor and losses in transmission were concerned. The different headings in the table here shown are deduced from another table not here published, the columns of which were as follows:

FIG. 27
Locomotive Used in Test No. 58.

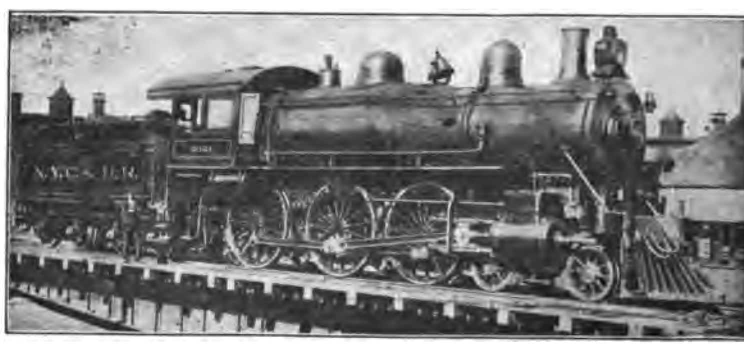


FIG. 28
Type of Locomotive Used in Test No. 7.

FIG. 29
Type of Locomotive Used in Test No. 56.

Column A.—*Total Cost of Entire Installation.*—Erected complete, consisting of power-house, transmission circuits, feeders, sub-stations, track construction chargeable to electrical equipment, overhead construction and electric locomotives.

Column B.—*Total Operating Expenses per Annum.*—Including wages in power-house and sub-stations and on rolling stock, together with all coal, oil, water, waste, repairs, etc.

Column C.—*Fixed Charges per Annum.*—Including interest at 4% on total investment, and taxes at 2% on buildings, sites, machinery and electric locomotives.

Column D.—*Total Expenses per Annum.*—Made up of Column B plus Column C.

Column E.—*Operating Expenses per Annum at Power-House.*

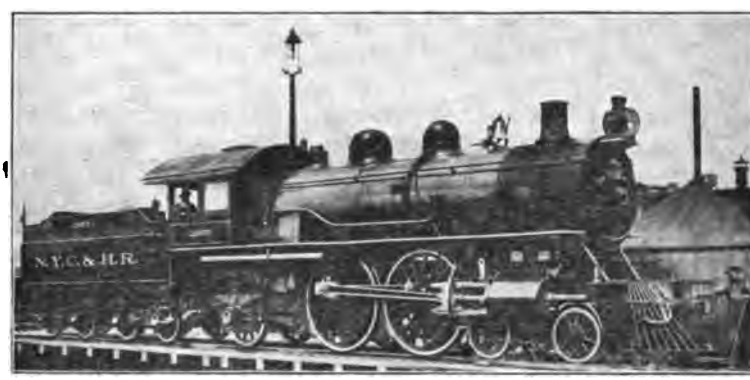


FIG. 80.
Type of Locomotive Used in Test No 6.

—Including coal, water, oil, waste, etc., and repairs and wages.

Column F.—*Operating Expenses per Annum at Contact Shoe.*—Including coal, water, oil, waste, etc., and repairs and wages in power-house; oil, waste, repairs and wages in sub-stations; and repairs (labor and material) on transmission lines.

Column G.—*Total Expenses per Annum Exclusive of Rolling Stock.*—Including operating expenses per annum at contact shoe (as in preceding Column F) plus fixed charges as follows: interest at 4% on total investment (less cost of electric locomotives) and taxes at 2% on buildings, sites and machinery.

Column I.—*Total Locomotive Miles per Annum.*—Determined from information furnished through the Operating Department.

The explanation of the columns in Table 4, page 653, is as follows:

Column H is

$$\frac{\text{Column E (of table not published)}}{\text{Total k.w. hours generated at power-house.}}$$

and represents the operating expenses per k.w. hour at power-house switchboard.

Column M is:

$$\frac{\text{Column F (of table not published)}}{\text{Total k.w. hours delivered to contact shoe, annually,}}$$

and represents the operating expenses per k.w. hour at contact shoe.

Column N is:

$$\frac{\text{Column G (of table not published)}}{\text{Total k.w. hours delivered to motor terminals annually,}}$$

and represents the *total cost per k.w. hour delivered to motor terminals, exclusive of fixed and operating charges on electric locomotives.*

The cost per k.w. hour at motor terminal differs from the cost per k.w. hour at the contact shoe only when batteries are carried on the locomotives, in which event the cost per k.w. hour at the motor terminals is increased over the cost per k.w. hour at the contact shoe by the cost of energy lost in the batteries.

Column J is:

$$\frac{\text{Column B (of table not published)}}{\text{Column I}}$$

and represents the operating expenses per electric locomotive mile. The values in this column are directly comparable with values now obtained in the present steam locomotive service, except that the operating expenses for steam locomotives as shown by the performance sheets of the Motive Power Department do not include any charge for water. From the best information available, the cost for water for the present service on this division is about .987 cents per locomotive mile, which amount added to the present cost as shown on the locomotive performance sheets, gives an amount which should be compared with the values in Column J.

Column K is:

$$\frac{\text{Column C (of table not published)}}{\text{Column I}}$$

and represents the fixed charges per electric locomotive mile, and is here tabulated merely as a step in obtaining.

TABLE IV.—Table of Estimates on Plans for Proposed Electrical Equipment of the N. Y. C. & H. R. R. R. Between Grand Central Station and Mott Haven Junction.

Plan.	CHARACTER OF STATIONS ETC	Operating expenses per k.w. hour at Power-House Switchboard. $H = \frac{E}{\text{Total k.w. hours at power-house}}$	Operating expenses per k.w. hour at Contact Shoe. $M = \frac{F}{\text{Total k.w. hours at contact shoe}}$	Total cost per k.w. hour at Motor Terminals. $N = \frac{G}{\text{Total k.w. hrs. at motor term's}}$	Operating Expenses per Locomotive Mile $J = \frac{B}{I}$	Fixed Charges per Locomotive Mile. $K = \frac{C}{I}$	Total Charges per Locomotive Mile. $L = (J+K)$
1.	Direct current power station at center of line and contiguous to tracks. 600-volt working conductor, no batteries	.447c	.60c	1.06c	14.02c	6.58c	20.60c
2.	Same as No. 1, with batteries in power-house	.472	.66	1.137	14.65	6.71	21.36
3.	Same as No. 1, with battery sub-station near Grand Central Station and Mott Haven Junction	.475	.668	1.20	14.7	7.25	21.95
4.	Alternating current power-station on river front near center of line, with rotary converter sub-stations near each end of line. 11,000 volt A. C. and 600 volt D. C.	.572	.715	1.287	15.2	7.58	22.78
5.	Combined D. C. and A. C. Power station at Harlem River near one end of line and one rotary converter sub-station near the other end of line. 11,000 volt A. C., 600-volt D. C., no batteries	.570	.666	1.19	14.7	7.18	21.88
6.	Direct current feeders from Manhattan Railway sub-station located near center of line. Transmission from sub-station to working conductor, 600 volts D. C. energy to be purchased	2.5	2.650	2.748	34.64	2.89	37.53
7.	Rotary converter sub-station at center of line. A. C. energy to be purchased from Manhattan Sub-station and transmitted at 11,000 volts. Energy to cost ½ cent less per k.w. hour than D. C. energy delivered	2.5	2.336	2.508	31.50	4.23	35.73
8.	Two rotary converter sub-stations, one near each end of line. A. C. current to be purchased from Manhattan sub-station near center of line	2.1	2.336	2.504	31.50	3.93	35.43
9.	Combined A. C. and D. C. power station near Harlem River at end of line. One sub-station near other end, and batteries carried on locomotives charged from working conductor	.519	.629	1.122	16.58	7.76	24.34
10.	One rotary converter sub-station near center of line, A. C. current purchased from Manhattan sub-station No. 7, batteries on locomotives charged from working conductor	2.12	2.4	2.502	34.40	4.08	38.48
11.	Direct current feeders from Manhattan sub-station No. 7 near center of line. Batteries on locomotives charged from working conductors	2.5	2.738	2.742	37.81	2.51	40.32
12.	Combined A. C. and D. C. power station at Harlem River near outer end of line. One sub-station near other end. Batteries in power station and sub-station. A. C. transmission 11,000 volts. D. C. conductors 600 volts	.55	.775	1.335	15.80	7.83	23.63

Column L (which is Column J plus Column K) and represents the *total cost per electric locomotive mile.*

While the results in Column L of Table 4 indicate that Plan No. 1 was the most advisable one to adopt, it was not seriously considered for the reason that it necessitated locating the power station in a part of the city where its erection would probably have been prohibited by the city authorities, but it was here introduced for comparison as indicative of the economy to be gained by placing the power station at the theoretical center of distribution. The same objections apply to Plans 2 and 3.

Plans 4 and 5 bring out quite clearly the difference in the cost of operation between two sub-stations and one, both plans permitting the location of the power station on the river front.

The difference in favor of Plan 5 is entirely due to the saving in labor of one sub-station.

Plans 6, 7 and 8 were studied with the object of ascertaining whether the purchase, instead of the generation of power, would offer a satisfactory solution of the problem.

The purchase of both D. C. and A. C. energy was considered on the lowest basis that it was thought possible for any existing company to furnish it, and it was found that the D. C. energy would cost the railroad company one-half cent more per k.w. hour than the A. C. energy, in consequence of the interest, depreciation, maintenance, etc., of the transmission lines, rotary converters and other sub-station apparatus which would have to be furnished by the energy producing company.

The prohibitive annual cost of these purchasing plans is at once obsérved by reference to Columns L and M, the plans only meriting consideration as representing a temporary arrangement that might be effected in order to allow rapid installation.

Owing to the more or less complex system of overhead or third rail yard construction made necessary by the nature of the case, and the advantages to be obtained by their elimination in the substitution of locomotives which could, for switching service, be self-contained, though normally supplied with energy from the working conductors, a study was made of electric locomotives carrying batteries.

The results of these studies made under several different assumptions are shown under Plans 9, 10 and 11. From Columns L and N it is evident that whatever may be gained by the elimination of the overhead construction is largely offset by the additional cost of operation, although it will be observed that the cost per locomotive mile of Plan 9 compares favorably with the cost in Plan 12.

Plan 12 differed only from Plan 5 in a slight reduction in the capacity of the converting apparatus in the power-house and sub-stations and the substitution therefor of two storage batteries (one located in or near the power-house and one in the sub-station) each of such capacity that it, together with only a portion of the main station and sub-station machinery, would be capable of taking over the entire load of the line for a short period of time in cases of emergency.

The additional first cost and the slight increase in annual expense (as compared with Plan 5) represented by a reserve station capacity of this nature, was thought to be of secondary importance only, in view of the increased reliability of operation thereby obtained. The increased cost of operation in this plan over that of Plan 5 is due to the fact that the battery maintenance was figured at 10% per annum, which is somewhat higher than is ordinarily assumed, and will probably be considered excessive by some.

A battery of this kind would not only serve as a reserve but would prove of considerable value as a regulator of potential along the line, and in addition it would, notwithstanding its inherent losses, tend to reduce the power-house operating costs by taking up the excessive load fluctuations of the system and permitting the load upon the engines to be maintained at or near their most efficient working capacity.

It was considered of the utmost importance in an installation of this magnitude that the number of interruptions of power supply be reduced to a minimum, that no device which could increase the safety and reliability of the plant should be omitted, and that the probability of future extensions of the electrical system should be considered. As best fulfilling the above conditions, therefore, Plan 12 was the one specifically recommended for adoption.

Operating Expenses.

A careful compilation of all the expenses entering into the operation of the present steam service was made, and the following comparative table (Table 5) of relative costs is believed to be correct, assuming that the present locomotives running between Mott Haven Junction and Grand Central Station should be abandoned and the service now performed by them duplicated by electric locomotives operated in accordance with Plan 12. It is assumed that the electric locomotives will be operated by the same class of men as those who now operate the steam locomotives and that they would receive the same rate of pay that they now receive.

This condition is not favorable to electric traction, as it is not ordinarily necessary to have two men to operate an electric motor, but in the writer's judgment, it is not advisable to operate a service of this class under such exacting conditions without two men on each locomotive.

If the motor car system should be adopted, as it probably would be were the electrical equipment extended beyond Mott Haven Junction or if the forward guard or brakeman were allowed to take the place of the second man while passing through the tunnel and yards, a saving equivalent to his wages could thereby be effected.

With two men of the same skill as at present employed on the locomotives, the figures are as follows:

TABLE V.

	Steam	Electricity
Operating expenses per locomotive mile exclusive of fixed charges but including water, labor, cost of cleaning and repairing tunnel, and all other expenses of locomotive operation - - - - - - - -	23.05	15.80
Fixed charges per locomotive mile assuming that it now requires 40 locomotives to perform the present service and that 33 electric locomotives could perform the same service -	1.13	7.83
Total in cents - - -	24.18	23.63

From these figures it appears that while there would be a slight annual saving in operating expenses in favor of electricity, it is not sufficient to warrant its adoption on the grounds of economy in operation alone, although its adoption can be justified on other grounds.

These figures could be made more favorable to electricity were an optimistic view of many of its advantages taken, and the probability is that practical operation will show a somewhat greater gain than here indicated, but it has been deemed best by the writer to maintain a conservative view throughout the entire investigation.

It is, however, safe to conclude that the saving in operating expenses by the electric system would be sufficient to offset the increased fixed charges due to the additional investment made necessary by its adoption.

The dynamometer car was operated by Edward C. Schmidt, Professor of Railway Mechanical Engineering of the University of Illinois. He was assisted by Messrs. J. J. Snodgrass and R. W. Lohmann.

Messrs. B. S. Harrison, Hugh Hazleton, R. W. Lohmann, J. J. Snodgrass, H. A. Strauss, and A. S. Courtright, assisted in the calculations and preparation of the report.

In connection with the investigation, a series of comparative acceleration tests of steam locomotives and electrical equipment were made at Schenectady, the results of which are set forth in another paper prepared by Mr. W. B. Potter and the writer, which is to be read at this convention.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 19th, 1902.

NOTES ON THE PLOTTING OF SPEED-TIME CURVES.

BY C. O. MAILLOUX.

The most practical way at present known of studying and analyzing electric railway problems, is by means of curves depicting the relation between the various factors or quantities which influence the conditions or affect the results, and showing how these factors and quantities vary with respect to each other or with respect to the time, the speed, the electric energy, or some other determining feature or circumstance of the case.

The precise determination of most of the important factors entering into the problem in any specific case, for instance, the electric power input, energy consumption, capacity and characteristics of motor equipment, station equipment required, heating of motors, line losses, etc., etc., for a given electric railway service, involves the general problem of not only determining what actually does take place, but also of predetermining what may, should and must take place, at every successive interval of the total time consumed in an average run between two successive stations or stopping points, or, what is still better, at every instant of time during the entire trip, with each kind of car or train to be used for and in the said service.

The speed-time curve is the key to the solution of this general problem. It is the important connecting link whereby the relationship between the various factors and quantities aforesaid is established and verified. It constitutes, in most cases, an important and essential—one may say, indispensable—preliminary step in the study and solution of new and complex electric railroad problems, for the reason that many of the factors involved can be determined or evaluated with precision only by its assistance, and could scarcely be determined at all without it.

The use of a curve substantially equivalent to a speed-time curve was suggested in connection with certain problems of steam locomotive propulsion, as early as 1890, in Godwin's "Railroad Engineers' Field Book." This suggestion was commented upon favorably in an article published in the *Railroad Gazette*, at the time, (Volume XXII, 1890, pp. 731-732). It does not appear, however, that much, if any, practical use was made of this idea in subsequent discussions of railway problems. It is only within the last five or six years, and entirely owing to the efforts of electrical engineers to substitute rational for empirical methods in electric railroad engineering, that the speed-time curve has been thought of seriously or used practically in connection with electric railroad problems. The idea of thus using the speed-time curve seems to have suggested itself to, and to have been utilized by, several individuals, independently, at about the same time. It was used in January, 1898, by Mr. S. T. Dodd and the writer, who collaborated in the preparation of certain estimates, charts, data, etc., forming part of a report on an electrical equipment for the Manhattan Elevated Railroad of New York. The importance and the value of the curve were not generally understood or appreciated by electric railway engineers, however, until Mr. A. H. Armstrong read his able and interesting paper on "Some Phases of Rapid Transit Problems" at the Omaha meeting of this INSTITUTE in June, 1898. In that paper, the utility of the speed-time curve in the study of railway problems was demonstrated by Mr. Armstrong in a brilliant and convincing manner, and the curve has since become recognized as a very useful means of analysis in dealing with such problems.

Speed-time curves have been used in two different ways: first, as a method of approximation or generalization for the determination of rules and data pertaining to, and useful in, abstract or general cases; second, as a method of precision for the exact determination of rules and data in individual or concrete cases, and also as a criterion or test of their fitness for, and applicability to, such cases.

The process of plotting these curves is much less difficult and tedious in the first case than in the second case. The reason is that in generalizing or in dealing with abstract cases, the use of certain hypotheses or assumptions capable of simplifying methods is admissible; whereas, in dealing with an individual case, all hypotheses or assumptions not strictly consistent with the actual facts of the case should be eliminated in order that the method may lead to correct and reliable results.

As might be expected, the speed-time curve is influenced and complicated by certain features and conditions characteristic of each individual case, which ought to be taken into account in order to attain accurate, reliable results. When properly plotted so as to truly represent all the factors which influence it, the curve becomes a valuable instrument of precision by means of which the practical results to be anticipated in the particular case under consideration, may be analyzed, checked, criticized and corrected with accuracy and confidence. These factors include the various constituents or components of that complex resultant called "train resistance," also the track gradients, track curvatures, train inertia (linear and rotational), capacity and gearing of motors, current limit, voltage, etc., etc. In dealing with a general case, however, the engineer may greatly simplify the task of assorting these influencing factors, and of assigning the proper value to each, by making assumptions regarding some of them. The usual process of simplification is to make one or all of the following assumptions: That the line is absolutely level and tangent (straight); that the train resistance is constant at all speeds; and that all runs between stopping points are of the same length. It is needless to say that these idealized conditions are never all realized conjointly in any practical case. Consequently, the more the conditions of the actual case depart from these idealized conditions, the less the reliance that should be placed upon conclusions and data obtained by methods involving the assumptions aforesaid. It is, unfortunately, not always easy to determine the point at which the simplified method should no longer be trusted in dealing with a practical case. The assumptions made usually lead to incorrect instantaneous speed values at certain points of the acceleration curve, and these errors tend to vitiate the subsidiary curves derived from the speed curves, such as, for instance, the power input curve, whose ordinate values depend upon the speed values. These errors in the power input curve and in the energy consumption calculated therefrom, are likely to affect the motor equipment and the generating station equipment provided for a given service, since the calculations and conclusions regarding them are based upon these subsidiary curves. A relatively small discrepancy between the idealized and the actual conditions may lead to radically different conclusions and results in these respects, thereby influencing greatly the total cost of equipment, and re-acting seriously upon the capital investment, and the fixed charges involved in the project. Such cases have actually happened.

The " second way " or the use of the speed-time curve as a " method of precision " in concrete practical cases, while a trifle more troublesome, will, in the majority of cases, undoubtedly prove more satisfactory, and less expensive in the end. The truth is, that the practising engineer is very seldom called upon to deal with abstract or general cases. It might be said that every individual case becomes a specific, concrete case, very soon after the engineer begins the process of analyzing and studying it.

The object of this paper is to facilitate the use of speed-time curves as a " method of precision " by contributing certain notes of theoretical and practical observations bearing upon its analysis, or the study of its characteristics, and upon its synthesis, or the principles involved in plotting it.

Technical Definitions.—The generic term " speed-time curve " as used in this paper, is understood to denote any curve showing the velocity of a car or train at successive intervals of time. Figs. 1, 2 and 3 show three different kinds of speed-time curves. In plotting these curves, the horizontal distances or abscissæ are generally used to represent time values (in seconds), and the vertical distances (ordinates), are used to represent speeds (usually measured in miles per hour in this country, and in kilometres per hour wherever the metric system is used).

The curve, in each case, not only shows the speed attained at any given interval of time, but it also shows the variations in speed occurring at various intervals of time. The slope of the curve at any time point is an indication and a measure of the time-rate of change of speed at the corresponding instant of time; and it shows whether the speed is constant, or increasing, or decreasing.

A horizontal speed-line indicates constant or uniform speed. An upward slope in the speed-line indicates increasing speed, or *acceleration*; a downward slope indicates decreasing speed or *retardation*. These characteristics serve to distinguish the different kinds of speed-time curves.

The term " acceleration curve " is usually restricted to curves, or portions of a curve, in which the speed is increasing, or, at least, remaining constant or nearly constant. Such curves correspond to the portions of time during which power is being applied to the train so as to increase the speed or to keep it constant (Fig. 1).

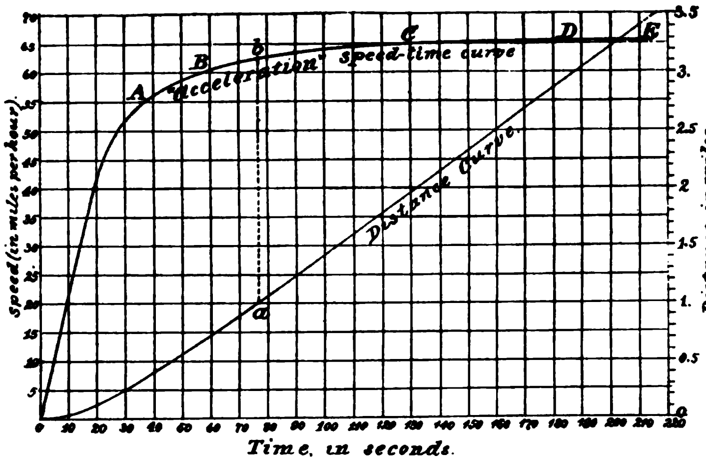


FIG. 1.—Typical Acceleration Curve.

The " retardation curves " are of two kinds, corresponding to different rates of retardation.

The term " coasting curve " or " drifting curve " is used to designate speed-time curves, or portions thereof, corresponding

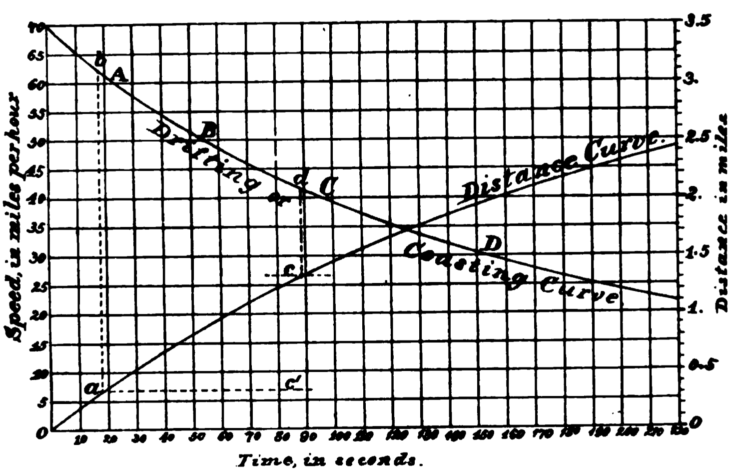


FIG. 2.—Typical Drifting or Coasting Curve.

to intervals of time when the car or train is moving by its own momentum only, and when the rate of retardation is relatively small (Fig. 2).

The term " braking curve " is applied to speed-time curves, or portions thereof, corresponding to intervals of time when the speed is being purposely reduced by means of brakes,and when the decline or decrease in velocity is relatively rapid (Fig. 3).

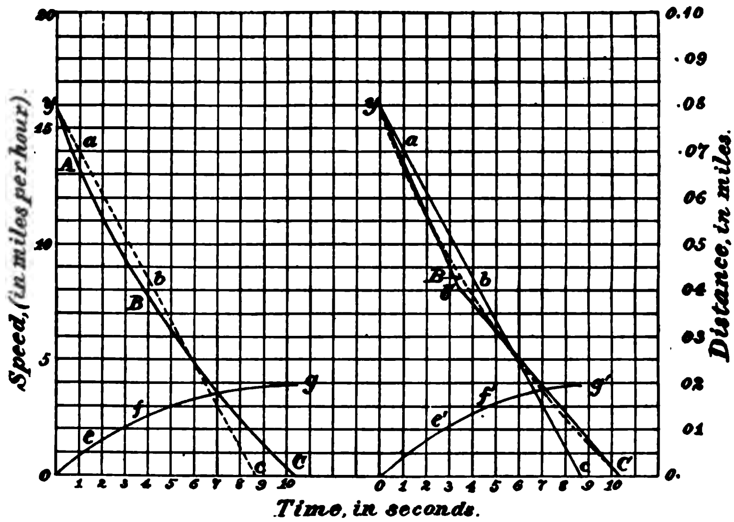


FIG. 3.—Braking Curves.

The term " run curve " is often used to denote a speed-time curve showing all the changes in the speed of a car or train from the time it starts until it stops at the next station or stopping-point (Fig. 4).

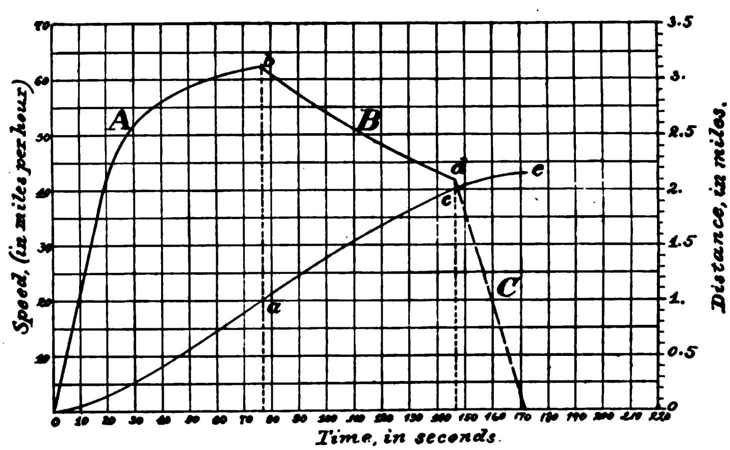


FIG. 4.—Typical " Run Curve."

The first portion of every " run " curve, or the portion during which the train is gaining speed, is an " acceleration " curve. The " run " curve usually, but not always, contains a portion which is a coasting or drifting curve, and it also generally contains a portion which is a braking curve.

The terms " velocity " and " speed " are used as synonymous terms in this paper.

Analytical Definitions.—A certain knowledge of the physical nature and mathematical properties of the various time-function curves mentioned in the previous section is essential for the proper, intelligent use of these curves, and is presumed to be possessed by those who make practical use of them. The precise definitions of these various curves, and the analysis of their properties, involve the analytical study of motion, more especially rectilinear motion. For the convenience and benefit of those who may wish to refresh their memories, or who may wish to go more deeply into the subject (no general treatment of the subject having as yet been published), a brief summarized analytical study of time-function curves, more especially the distance-time and speed-time curves, is given separately at the end of this paper, in Appendix A.

The derivation of the fundamental formulæ relating to train acceleration, constituting the extension of this analytical study, is given in Appendix B.

Appendix C and Appendix D contain the derivation of certain formulæ which are of use and convenience in plotting the " run " curves. These formulæ are not generally known. It is hoped, in this way, to make the paper useful and interesting to those " who wish to know " as well as to those who " already know," the ground-work of the subject.

Appendix E discusses the adaptation of the formulæ to " metric" speed-time curves.

I.—Analysis of Train Motion.

The motion of a car or train under actual or assumed service conditions constitutes an aggregation of different forms or phases of motion.

The " run curve," which graphically depicts the train motion, is, therefore, a " resultant " curve. The analysis of the motion involves the separate determination and segregation of the elementary or fundamental forms of motion, which constitute the components of which the resultant motion is made up.

A glance at a run curve shows three distinct characteristic kinds of lines, which correspond to distinctive phases or kinds of motion, namely, the motions characteristic of acceleration, coasting (or drifting), and braking, respectively.

In Fig. 4 the curve $O\,b\,d$ is a " run " curve of the simplest character. The first portion (A) is a simple acceleration curve. The second portion (B), is a drifting or coasting curve, and the final portion (C) is a braking curve. The acceleration portion (A), is the same as the corresponding portion of the acceleration curve in Fig. 1, from which it was taken. The vertical dotted line (a - b), indicates the point at which the acceleration line was cut off. In like manner, the drifting curve portion of the run curve in Fig. 4, was taken from Fig. 2, between the points corresponding to the same letters (b-d) The vertical dotted lines, (a-b, c-d) indicate the points at which this curve was cut off. The braking portion (C) of the curve in Fig. 4 was calculated.

This particular run curve corresponds to a case in which the power is applied to the car only once, or during the early portion of the run. In actual practice, however, it is often found necessary to allow, or to purposely cause, the speed to diminish, and to subsequently cause it to increase again, at intermediate points of the run. In such case, the run curve will show "notches" or "humps." (Fig. 13.) These notches or humps are almost always due to the occurrence of track curves having a relatively high degree of curvature at points intermediate between stopping points. These curves impose a limit on the speed which it is safe to maintain at such points of the line. When such curves occur at or near the stations, they have less influence on the form of the run curve, because the speeds are lower, owing to the starting and stopping of trains. In such cases they do not cause humps or notches in the run curve, although they do affect the " angle " of the acceleration or of the retardation (braking) curve. The notch or hump in the run curve indicates the fact that acceleration again takes place after the speed has been reduced to the proper or desired limit. This acceleration is followed by drifting and braking, and, in some cases, the run curve may contain several such notches, each of which, as will be readily understood, corresponds to what might be called an " acceleration cycle."

Acceleration.—Each acceleration cycle of a service run, corresponds to the time during which energy from some source is applied to the car or train, so as to cause the speed to increase.

(The physical and mathematical characteristics of acceleration are discussed, summarily, in Appendix A and in Appendix B.)

The energy imparted to a train during an acceleration cycle is absorbed and disposed of by the train in two ways: First.—A portion of it is immediately converted into heat, which represents the energy required and expended in overcoming the various frictional resistances making up what is called " train resistance." Second.—A portion is *stored* as mechanical energy in the " mass " of the train. This stored energy is the energy required either (*a*) to produce acceleration, in which case it is stored as kinetic energy, or (*b*) to lift the train on an " up-grade," in which case it is stored as potential energy. The two forms of stored energy often occur simultaneously. When accelerating on a " down " grade, the stored energy at any instant would, evidently, be equal to the difference between these two kinds of energy at that instant.

The energy concerned in acceleration may be classified under three general heads, namely:

1. The energy required for overcoming the actual mechanical resistance to the motion of the car.

This energy is immediately dissipated as heat.

2. The energy required to overcome grades.

This energy is stored as potential energy.

3. The energy required to overcome the inertia of the car and give it momentum.

This energy is stored as kinetic energy.

The third form of energy, namely, kinetic energy, is the only form usually recognized as being concerned in producing and entering into acceleration. It can be shown, however, that in any case in which acceleration occurs, all other forces than that of kinetic energy may also be estimated in terms of an acceleration, which may be termed " equivalent " acceleration. This has been done in Appenidx B, in equations (24) to (29), by means of which an important theorem is deduced, to the effect that the total acceleration in a moving mass is the algebraical sum of the individual accelerations corresponding to each of the forces acting to produce or prevent the motion of the body. This theorem is doubtless well known in kinematics, although its application to the speed-time curve appears to be new. It is one of those principles which, though not at first readily apparent and somewhat difficult to work out, prove to be really very simple to understand and to apply. According to this theorem, the second form of energy, or the energy required to overcome grades, may be estimated in terms of equivalent acceleration. It is known, as a matter of fact, that the potential energy, or energy of position, in a car which is on a " down " grade, can produce the same acceleration that could be produced by an equivalent tractive effort in pounds per ton, applied to the car in any other way. Conversely, the motion of the car in the contrary direction would produce a contrary effect, or a reduction of acceleration, which could be expressed in terms of equivalent *loss* of acceleration.

Energy of the first kind cannot, strictly speaking, be said to be capable of producing an acceleration. It may, nevertheless, be expressed in terms of " equivalent " acceleration, since, as in the case of a car going up grade, it may be considered as equivalent to a force occasioning a *loss* of acceleration.

In the same manner and by analogy, we might consider the kinetic energy absorbed in pure acceleration as an energy required to overcome an apparent increase in the train resistance due to the inertia of the train, and in like manner, the energy required to overcome grades might be also ascribed to an apparent increase in the train resistance. From this standpoint, the three forms of energy may be considered as having the same kinemetical character. The energy corresponding to an actual resistance represents energy necessarily lost, or which is not recoverable, while the energy corresponding to a " spurious " resistance (analogous to "reactance" in electro-kinetics), represents energy which is not primarily or necessarily lost, but which is really stored, and which is recoverable, wholly in theory, and partially in practice. The former is analogous to the electrical energy dissipated by an " ohmic " resistance, and the latter to the " wattless " energy absorbed provisionally by a "reactance,"—the analogy being so obvious as to require no further explanation.

An acceleration curve is, as pointed out in Appendix A, a speed-time curve, or velocity curve, having a *positive* differential coefficient. This differential coefficient, as shown in Appendix B, in equation (28), is equal to the algebraical sum of the differential coefficients corresponding to the various forces concerned and active in producing the acceleration.

Using the letter " k " with suitable affixes, to designate the individual coefficients corresponding to the individual forces concerned in each case, and using the letter A' to designate the resultant acceleration, we have, from equations (28) and (29) in Appendix B.

$$\frac{dv}{dt} = k \pm k' \pm k'' \pm \text{etc.} = A' \qquad (I)$$

Some of these individual coefficients may be positive, while others may be negative, but the algebraical sum, according to the above definition of an acceleration curve, must be a positive number.

When weights (W) are expressed in tons of 2,000 lbs., and when p = the "equivalent" gross tractive effort or pull corresponding to each of the individual forces concerned in the resultant motion, we have, by analogy to equation (21a) in Appendix B,

$$k = \frac{dv}{dt} = .01098\,\frac{p}{W} \qquad (II)$$

and, reconstructing equation (I) accordingly, we have

$$A' = .01098\,\frac{p}{W} \pm .01098\,\frac{p}{W} \pm .01098\,\frac{p}{W} \pm \text{etc.}$$

of which the simplest form is

$$A' = \frac{.01098}{W}(p \pm p' \pm p'' \pm p''' \pm \text{etc.}) \qquad (III)$$

The factor $\frac{.01098}{W}$ is sometimes written $\frac{1}{91.1\,W}$.

When each term "p" is taken in lbs. per ton, the term "W" disappears, and we then have

$$A' = .01098\,(p \pm p' \pm p'' \pm p''' \pm \text{etc.}) \qquad (IV)$$

We must now determine the number and character of the force factors ("p"), by reference to which the resultant acceleration is to be expressed.

The force of the "equivalent" acceleration corresponding to train resistance could be expressed by a single symbol, but it is more convenient to express it by means of two separate symbols, one of which (f), shall correspond to, and shall include, all the factors of train resistance except the increase of resistance due to curvature, which latter may advantageously be considered separately, in which case its equivalent force may be expressed by the symbol "c." The force corresponding to grades may be expressed by the symbol "G." The force corresponding to kinetic energy may be expressed by the symbol "I." In this case, however, the effect is complicated by the fact that in a moving train there is inertia of two kinds, namely, linear inertia or the inertia due to the entire mass of the car moving in a straight line, and rotational inertia, or the inertia due to the rotating parts of wheels, gears and motors, It is possible, however, to express the rotational inertia in terms of linear inertia. This fact was alluded to in the paper read before this INSTITUTE by Mr. N. W. Storer, in which it is stated that the rotational inertia has the same effect in increasing the total inertia, as if the mass of the car were increased by a certain percentage. This percentage varies in different cases, but Mr. Storer recommends that it be taken at about 10%. We may, therefore, use the same term to designate the effect of linear inertia or rotational inertia, if this term includes the proper correction for rotational inertia. It is just as simple, and it may be sometimes convenient to use a separate symbol (" i ") for the rotational inertia.

These several symbols express the forces which react upon and modify the propelling force applied to the car. The forces in each case are understood to be measured in pounds of pull per ton of train weight, this being the basis assumed in the fundamental equation (21a) in Appendix B. The propelling force of the motor may be expressed in terms of an equivalent gross tractive effort (P), (also measured in pounds per ton).[1] In the case of a series electric motor, this gross tractive effort depends upon the amount of current passing through the motor, and also upon the gearing ratio of the motor. The amount of current itself passing through the motor is, as is well known, a function of the speed; consequently the gross tractive effort of the motor is, itself, a function of the speed of the car.

Tabulating these symbols, we have

W = Weight of car or train (in tons of 2,000 pounds).

T = The total or gross traction (due to the current) per motor, (in lbs. or kilos).

P = $T \div W$ = Gross traction in pounds *per ton*.

f = Force expended in overcoming the friction of all kinds, (including axle friction, air and wind resistance, etc., but not including curve resistance), in pounds per ton.

c = The force expended in overcoming the additional resistance due to track curvature.

G = The equivalent traction due to grades. (This factor

1 When using the metric system the force would be expressed in kilograms per metric ton. See Appendix E.

will have + sign on *down* grades, and − sign on *up* grades).

I = The force expended in overcoming linear inertia.

i = The force expended in overcoming rotational inertia.

p = Resultant force expended in acceleration. $(=I+i)$.

The factors. f, c, G, I, i, are all expressed in pounds per ton of train weight.

From this it is seen that we have to consider a total of six (6) terms of the type " p."

The term " f " expressing train friction varies, as is well known, as a function of the train speed, same as the gross traction.

The term " c " varies with the degree of curvature. This term only occurs in those portions of speed-time curves which correspond to points on the run at which there are track curves. It is usual to assume this resistance as equivalent to from 0.7 to 0.9 pound per ton per degree of curvature. Thus, assuming a coefficient of 0.8, a track curvature of 5 degrees would increase the train resistance by an amount equal to 4 pounds per ton.

The term " G " depends upon the percentage of grade, and is constant for each percentage. For example, a grade of 1%, which means a rise of one foot per hundred, would be equivalent to lifting the train weight (W) one-hundredth of the distance, or lifting one-hundredth of the weight the entire distance. Each ton of 2,000 pounds would, therefore, occasion an apparent increase in train resistance equivalent to 20 pounds per ton.

From the above, it is seen that the value of G in any particular case will be

$$G = 20\,q$$

in which q expresses the percentage of grade.

The terms " I " and " i " together represent, as will be understood from the preceding discussion, the net force—or the force which is expended in acceleration, (and stored as kinetic energy).

We may retain the term " p " to express this net force, so that

$$p = I + i$$

If we substitute the above terms for the terms p', p'', etc., in equation (IV) we have

$$A' = .01098\,(P - f - c \pm G) = .01098\,p \qquad (V)$$

The signs of " f " and " c " will always be minus.

The sign of " G " will be + when the car is on a *down* grade, and it will be − when the car is on an *up* grade.

We thus see from equation (V) that the differential coefficient of an acceleration curve may be simplified in expression until it is equivalent to the algebraical sum of various factors representing "real" or "spurious" train resistances, multiplied by a constant. The algebraical sum referred to is nothing more than the net pull, since, if we equate the last two terms of the equation, the coefficient .01098 disappears, and we have, simply,

$$p = P - f - c \pm G \qquad (VI)$$

Each term, taken separately with the constant, indicates the equivalent acceleration corresponding to said term, expressed in miles per hour per second. Thus, in the case of the gross traction, (P) the quantity .01098 P would mean the acceleration in miles per hour per second, which would be obtained if it were not for the modifying factors, f, c and G.

Retardation.—In the second portion of each cycle of train motion, there is a stage of motion during which the car moves without extraneous power being employed, it being impelled by the kinetic energy previously stored in it during acceleration. The car is then said to be "drifting" or "coasting." The coasting or drifting motion would continue, with the speed in the meantime gradually diminishing, until the kinetic energy stored in the car or train has been entirely dissipated in overcoming the train resistances, when it will stop. When the rate of dissipation of the kinetic energy is purposely increased by friction shoes bearing against the car wheels, the retardation is more rapid, and the car is then said to be "braking." A braking curve is, therefore, a retardation curve showing a high rate of retardation.

A retardation curve may be defined as a velocity curve having a negative differential coefficient. (See Appendix A, last paragraph.)

In a coasting curve, the coefficient is relatively small; in a braking curve, it is high.

The same equations which apply to acceleration will apply to retardation. In this case, however, since power is no longer being applied to the car, the quantity "P" will be zero, and will, consequently, disappear from the equation. The only terms remaining will be f, c and G, so that the equation will now become

$$-A' = .01098\,(-f - c \pm G) = -.01098\,p \qquad (VII)$$

If there happen to be no curves or grades, the equation will be, simply:

$$-A' = -.01098\,f = -.01098\,p \qquad (VIII)$$

whence we have

$$-f = -p$$

or the force (p) due to the kinetic energy is exactly equal to the force required to overcome the train resistance (f). The minus sign indicates that the acceleration is negative, or that its rate is a decreasing one. The energy producing acceleration comes, of course, from the kinetic energy stored in the car. The rate of decrease of the speed will be exactly such as to produce the force p ($= f$), and no more. This is in accordance with equation (22) in Appendix B. It seems strange until we stop to consider the two following circumstances: first, that the only way in which the energy of the car can be dissipated, when braking, does not occur, is by means of the friction due to train resistance; second, if the speed variation could, in any way, become greater than that which corresponds to and develops a force equal to that of the train resistance (in accordance with equation 22), there would be a surplus of force, and this surplus could only be expended in producing acceleration, or in the re-acceleration of the car. It is evident, therefore, that the rate of retardation of the car must, of necessity, be exactly such as, and can be no more than, will suffice to cause the kinetic energy stored in the car to be dissipated at precisely the rate required to overcome the train resistance, and also the effect of track curve resistances, and of up-grades, if there be any. It is worth while to note that the case would be different if the car were running on a down grade, for, in this case, G is not equal to zero, but has a positive value, and consequently, represents a force which is, of itself, capable of producing acceleration. Under those circumstances, we should, therefore expect, and we find in practice, that a higher rate of acceleration is produced.

When braking the car, there is, as already stated, an additional retarding force. This retarding force, which may be designated by the symbol " B " enters in the fundamental equation with the negative sign, so that we have:

$$-A' = -.01098\,(-B - f - c \pm G) \qquad (IX)$$

In practice, it is usual to speak of a braking force of so many pounds per ton. For high-speed work, the value generally taken is $B = 150$. As pointed out in Section II, in discussing the subject of plotting braking curves, it is usual, for the purpose of simplification, to assume that this figure (150), also represents and includes the values of f and c, so that the equation, as used in practice, would generally be simplified to the following form:

$$-A' = -.01098\ (150 \pm G) = 1.647 \pm (.01098\,G) \qquad \text{(X)}$$

In the coasting curve, as well as in the braking curve, the effect of a down-grade, which makes the sign of "G" a plus sign, will be, evidently, to decrease the rate of retardation, while the effect of an up-grade, making the sign of "G" minus, will be to increase the rate of retardation.

The equation shows that the slope of the braking curve will depend, not only upon the value of the braking friction (B), but also upon the train resistance, also the track curvature and percentage of grade, if any.

The term "B" is generally assumed constant, and independent of the speed. This is not exactly true, however. The true braking curve (y, A, B, C in Fig. 3), is, like the drifting curve, more or less convex to the axis of "x," especially in the middle portion. The straight line (in Fig. 3) (y, a, b, c), indicates the (constant) rate of retardation that would be required to bring the car to a stop within the same *distance*. It will be seen that with a constant rate of retardation, the car would come to a stop a little sooner than is actually the case in practice. The data available from actual tests are still so meagre, and the analysis of them is so incomplete, that engineers are still obliged, however, to assume a constant rate of retardation in dealing with the braking curve. This point is again referred to in Section II.

In the foregoing equations, the individual acceleration coefficients which make up the resultant coefficients are represented by means of various terms indicating a force or pull in pounds per ton, multiplied by a constant. This has been done because of the established practice among engineers, of estimating the accelerating force in *pounds per ton*. The writer believes that a more satisfactory way would be to estimate acceleration in miles per hour per second, using equations of the type shown in equation (I) rather than those of the type shown in equation (IV.) The advantage of equation (I) is the fact that it gives the resultant acceleration in terms of the individual accelerations expressed in *miles per hour per second*. Translated into words, this equation means that the total or resultant acceleration is obtained by taking the difference between all the positive acceleration coefficients and all the negative acceleration coefficients The transition from one type to the other has been clearly indicated, and it is not necessary, therefore, to repeat the equations in the modified form. In plotting the curves by the method which will now be described, the values used are those obtained by equations corresponding to equations (*V*), (*VII*) and (*IX*), but patterned after equation (*I*).

II.

The Plotting of Speed-Time Curves.

The information and knowledge obtained in the preceding investigation of the nature and character of the three kinds of fundamental speed-time curves, namely, the acceleration curve, coasting curve and brake curve, is of much practical utility and convenience in the plotting of these curves, and also in the plotting of run curves, which, as we have already seen, are in reality made up by joining together various portions of acceleration, drifting and braking curves.

In this case we must, in a measure, reverse the process followed in the analysis of train motion, for, instead of separating the curve into its components, we must assemble these components synthetically, so as to produce the curve.

Preliminary Considerations.—There are certain considerations which enter into the discussion of every specific problem in train motion. These include many things such as the character and location of the railway lines to be operated, the nature, character and other characteristics and conditions of the train service required, etc., etc. These things react upon and determine the schedule speed, headway and other service conditions, which, in turn, together with the total weight of a loaded train unit, determine the character and capacity of motor equipment required per train unit. A complete analysis of all these characteristics and conditions is beyond the scope of this paper. The preliminary calculations, by means of which the first approximation is made in regard to the number and capacity of motors per train equipment, are also beyond the scope of this paper.

The purpose of this section of the paper will be fulfilled if we assume that the motor equipment has already been decided upon, since one of the principal practical applications of the speed-time curves, more especially the service run curve, is to test or gauge the qualities and fitness of a specific equipment, by furnishing information as to whether the proposed equipment is capable of doing the service required or wanted under the actual or assumed service conditions.

The plotting of the three fundamental speed-time curves will first be discussed, after which we will be better prepared to understand the process of plotting the run curve.

Acceleration Curves.—The acceleration curve of a car, being the criterion of the performance of this car and of its motor equipment, must be constructed by reference to the fundamental data relating to the performance of the particular electric motors used in the said equipment. These data are carefully determined by the motor manufacturers, by means of more or less comprehensive and elaborate special tests made for that purpose, and they are shown graphically on certain curves known as "motor characteristic curves" (Fig. 5), which usually give the relation between the various values of current (amperes) sent through the motor, and three different quantities namely, the tractive effort or horizontal pull (pounds) exerted by the motor, the speed attained (m.p.h.), and the efficiency obtained, corresponding to the current values. The currents (in amperes) are usually represented in these diagrams by distances measured horizontally, while the other three quantities are represented by distances measured vertically, each according to its own appropriate scale. The tests of which the curves are the graphical summary and representation, are based in each case upon a particular gear ratio, which is noted on the curve sheet. These curves are sometimes made for various gear ratios, but usually are made only for one or two particular gear ratios. By means of these curves, the curves corresponding to other ratios can be easily obtained.

These curves are usually based upon tests made at a standard voltage of 500 to 550 volts. If the voltage to be used in the case under consideration is greater or less than the standard voltage, a correction will be required in the speed values. The speed in a series motor is, as is well known, practically proportional to the potential difference at its terminals. Hence, an increase in the voltage will increase the train speed in proportion. If, for instance, in the actual case, a mean voltage of 600 volts were assumed, the corrected speed curve (*B*, in Fig. 5), would be one having ordinate values 20% greater at every point. The curve of tractive efforts (*A*. *B*.) would remain unchanged so long as the gearing ratio remained the same. A change in the gearing ratio has the effect of modifying both the tractive effort and the speed. If the gearing ratio is made such as to cause the train to run faster, that is to say, if the number of teeth in the driving or motor pinion is increased, while the number of teeth in the driven wheel or gear on the car axle is correspondingly reduced, the result will be to raise the

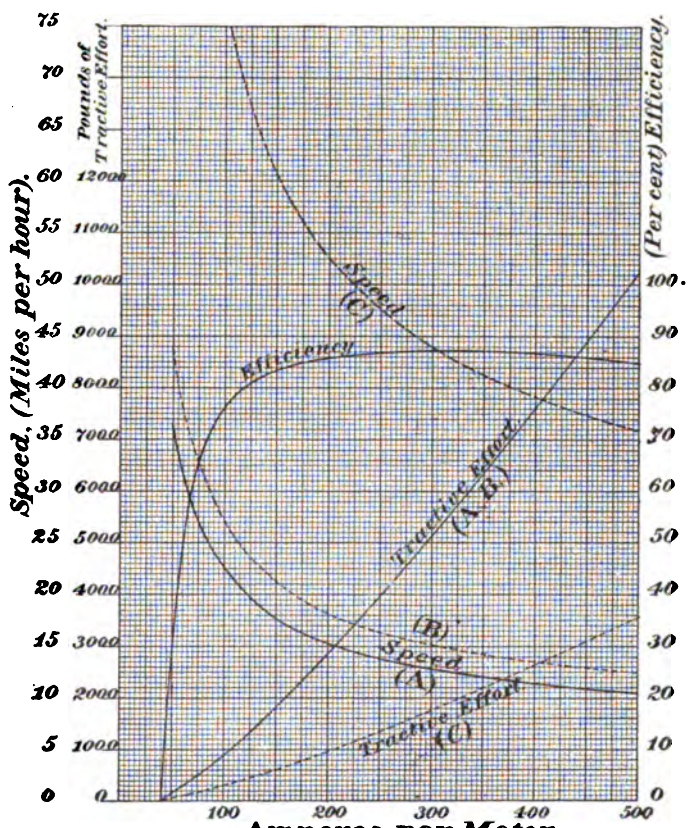


FIG. 5.

speed, while lowering the tractive effort; and vice versa. The corrected curves corresponding to each particular gear ratio, may be drawn and a new set of curves can be made for each change. This is not absolutely necessary, however, since the corrected values, both for speed and tractive effort, may be obtained direct from the original curves, by multiplying the values therein given by a suitable correcting factor or coefficient, as is well known. The speed correcting factor may include both the change in voltage and the change in gear ratio; or we may correct either of those two things separately. When a change is made in the gear ratio, a correcting factor will also be required for the tractive effort—this factor being equal to the reciprocal of the factor determining the change in speed, due to change in gear ratio. An illustration of the effect of change in voltage and in gear ratio on the motor characteristics is given in Fig. 5. In this diagram the speed curve drawn with solid line (A), is the curve showing the results obtained in the original shop test with a certain gear ratio and a mean voltage of 500 volts at the motor terminals. The dotted speed curve (B) shows the increase in speed which would result if the mean voltage were raised to 600 volts. As the gearing ratio remains unchanged, the tractive effort curve shown by the solid line, (A-B), would remain the same for both speeds. The speed curve drawn with broken line (C) indicates the speed values resulting from a change both in gearing ratio and in voltage. The change in gearing ratio in this particular case was such as to increase the relative speed of the car 2.87 times. The change in voltage being, as already stated, such as to increase it in the ratio of 600 to 500, or 1.2 times, it follows that the total increase of speed was

$$1.2 \times 2.88 = 3.46 \text{ times.}$$

In this case, the dotted line of tractive efforts (C) shows the tractive effort values which correspond to the speed curve (C). The coefficient, by which the values of tractive effort corresponding to the curve A must be multiplied, is, as already stated, equal to the reciprocal of the change in gearing ratio,

$$\frac{1}{2.88} = 0.347$$

The method of approximate determination of the gear ratio is passed over as being beyond the scope of this paper.

The various correcting factors, if any, having been determined and applied, in each particular case, substantially in the manner just indicated, the corrected values of tractive effort and speed corresponding to the various current values will now be known; and these values may be plotted in curves analogous to the corrected curves (C) in Fig. 5. Dividing the tractive effort values, which correspond to the various current values, by the total weight of train expressed in tons, we have the gross tractive effort per ton, which is the quantity " P " used in equation (V). Taking the speed values and the tractive effort values corresponding to the same current values, we may tabulate the tractive effort values as a function of the speed. On referring to equation (V), we see that we still need the values of the terms f, c and G. It is usual to begin by plotting the acceleration curve corresponding to a level and straight track. In such a case, the values of c and G both become zero. The values of the train resistance (f) are usually computed for different speeds, by means of some particular formula. The number of these formulæ is legion, but a completely satisfactory and comprehensive one still remains to be found. The latest and perhaps the most authoritative information on this subject will be found in some articles on " Train Resistance " in the *Street Railway Journal* for May and June, 1902.

By means of the two sets of values of P and f, and using the formula given in equation (V), the acceleration coefficients A', corresponding to various definite values of these quantities, and, therefore, to certain definite speeds, may be computed and tabulated. We then have two things, namely, the speed value and the acceleration coefficient corresponding to said speed. In the first method used for plotting speed-time curves, this is all the information that was required. The process of plotting consisted in drawing ordinates equal to the speed value, and drawing tangents to these ordinates equal to the acceleration coefficient—then displacing the ordinate to the right or left, until the tangent line met the tangent line corresponding to the ordinate of the previous speed point.

Reference to Fig. 6 will clearly show the general nature of this method. The process of plotting consisted in drawing ordinates such as y, y', y'', equal to various speed values, and then drawing at the upper end (A, B', C') of each of these ordinates, a tangent line whose angularity is proportional to the corresponding acceleration coefficient for each of these ordinates. The ordinates are then to be displaced sidewise (to the left, in this case), until the tangent line of any ordinate meets or crosses the tangent line corresponding to the ordinate of the previous speed point—that is to say, of the ordinate immediately to the left of it. The proper meeting points (m, n) between the tangent lines are to be determined by the eye, being located usually about halfway between the two corresponding ordinate points. The process might be illustrated by means of a file of soldiers of unequal height, with outstretched arms, and moving closer together until their hands touch. If the proper place of the tangent to the ordinate y in Fig. 6 is at the point A on the curve $OABC$, then the tangent lines B' and C' would find their proper places when the ordinates y' and y'' have moved to the left as far as the points B and C respectively. The curve $OABC$ osculating these tangent lines, as shown in the figure, would be the curve required. This method has serious drawbacks. In the first place, it is not easy to determine the proper points, m and n, at which the tangent lines should meet. The difficulty of accurately drawing the tangent line itself is already very great, without the difficulty of determining by the eye the distance at which the next ordinate should be placed. If, for instance, in Fig. 6 the tangent lines were made to meet at the points m' and n', corresponding to the mean ordinate, or half of the speed increment, instead of meeting at the exact points, m and n, the result would be to displace each

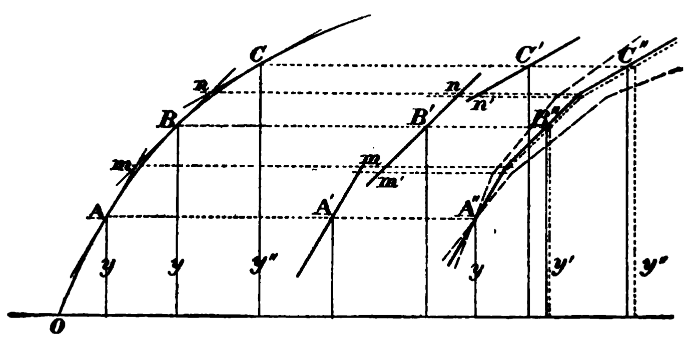


FIG. 6.

ordinate, as clearly shown at the right end of the diagram, where the solid tangent lines passing through the points A'' B'' and C'' represent the tangent lines in the same relative locations as the tangents at the corresponding points in the curve $OABC$, while the dotted lines represent the effect of changing the meeting point from the points m, n, to the halfway points, m' and n' respectively. The diagram also shows the effect of an error in the angle of the tangent line. This error is usually constant, being due to the particular method of drawing and the protracting instruments used. It is, therefore, apt to be a cumulative error. As clearly indicated by the broken lines, starting from the initial ordinate at the point A'', the diagram shows the increase in divergence resulting from a constant error in angularity, the effect being to make the curve too high when the angle is too large, and too low when the angle is too small. The errors due to the two causes might be cumulative, or they might tend to partially compensate each other. In the diagram it is clearly seen that, under the conditions shown, the errors would tend to compensate if the error in the angle of the tangent was such as to make this angle greater than it actually is, while they would be cumulative in the contrary case. The method is totally unscientific and unsatisfactory, notwithstanding the fact that it is still used. There is really no telling what the percentage of error may be. It is all conjecture and guess-work.

No method of curve plotting can be entirely satisfactory without some means of pre-determining *both* coördinates of each point to be plotted. The method of calculating the time increments, as analyzed in Appendix C, constitutes a great improvement on the method just described. The method is sufficiently described in Appendix C. By means of this method, using equations (*i*) and (*ii*), the time points corresponding to the various speed points, may be determined with any degree of accuracy desired. The conditions influencing the accuracy, and the error to be expected, in any case, are fully discussed in Appendix C. These time values having been tabulated, the curve may be plotted by locating the ordinates on a sheet of paper in the usual way. After obtaining the coordinates for an acceleration curve on a straight and level track, we can, by assuming proper values for G, in equation (V), obtain and tabulate the acceleration coefficients of other acceleration curves corresponding to various grades; and the time values corresponding to the various speed values having been computed and tabulated, these curves may be plotted. Fig. 7 shows a set of nine acceleration curves, including one for a level and straight track, four for up-grades of ½%, 1%, 1½% and 2% respectively, and four for the corresponding down-grades. This method, while more simple and far more accurate than the crude " tangent " method, still admits of improvement.

The method to be described has the advantage of being practically a graphical method, and of being comparatively simple and quick in practical use. Incidentally, it serves many useful purposes, by giving graphically and accurately, in readily intelligible manner, the answer to many questions, the answer to which otherwise necessitates and involves more or less tedious computations and some thought. The method is based upon the theorem given at the end of Appendix B, to which reference has already been made. It requires two charts, which may be

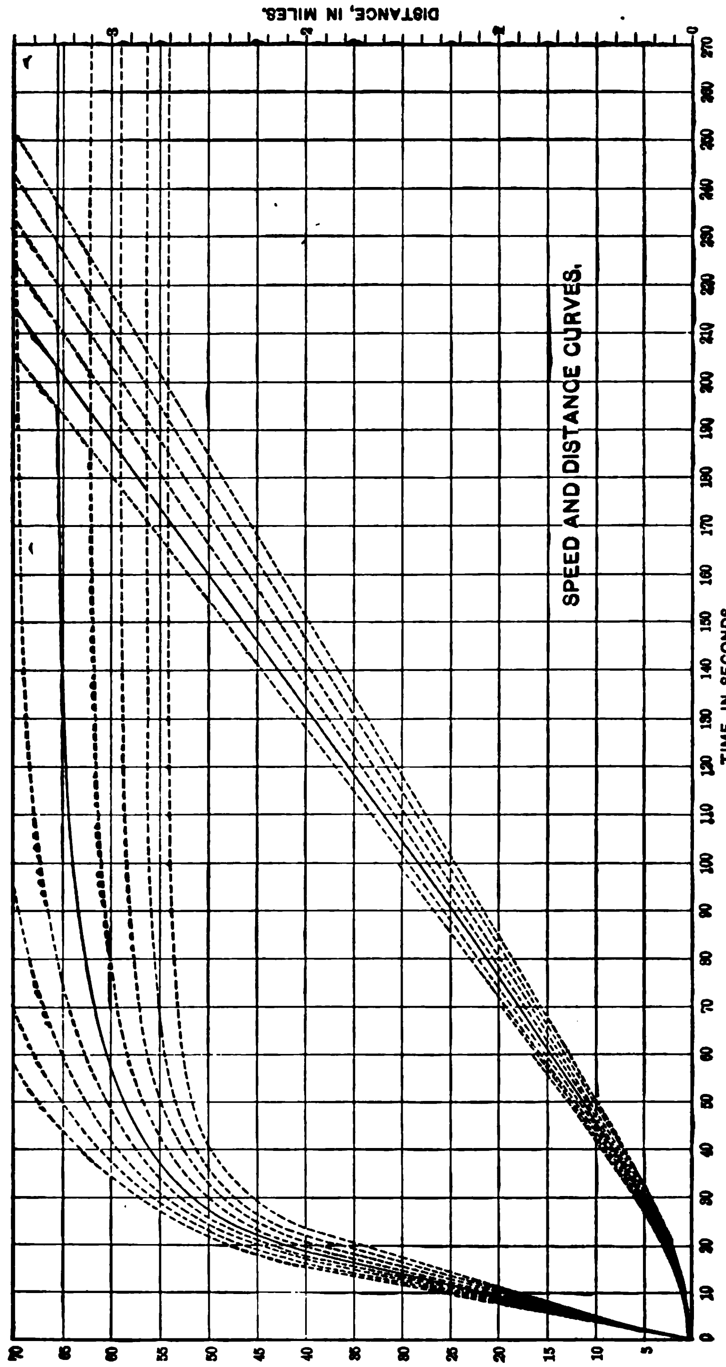


Fig. 7.—Chart of Accelerations.

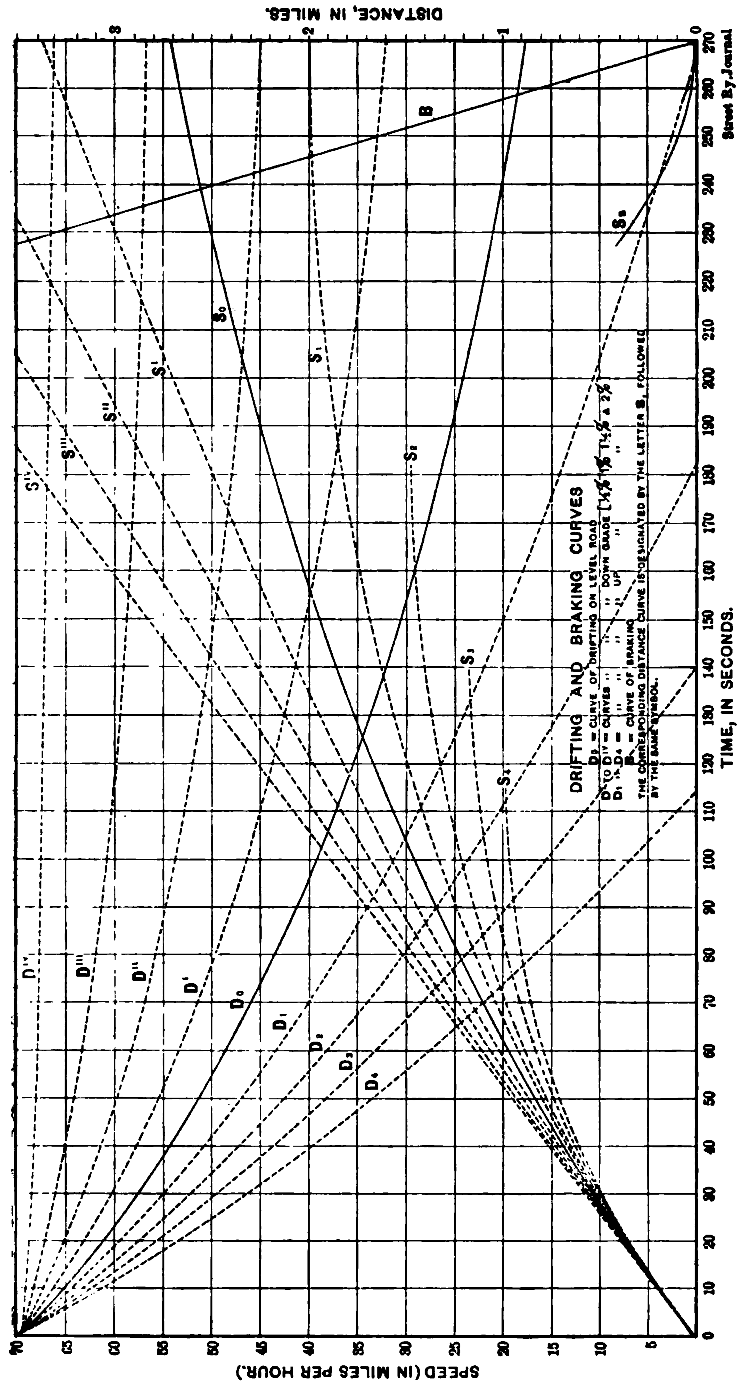


FIG. 8.—Chart of Retardations.

drawn either on separate sheets, or else combined together on the same sheet. These charts, are respectively, the " Chart of Coefficients," (Fig. 9) and the " Chart of Reciprocals " (Fig. 10.)

In the " Chart of Coefficients " the abscissæ represent speed values in miles per hour, and the ordinates represent acceleration coefficients, that is to say, the values of the differential coefficients $\frac{dv}{dt}=k$, ranging between zero and 2.5 miles per hour per second. On this chart are drawn various curves representing the variation of the acceleration coefficient, as a function of the speed. These curves are really curves of " equivalent " acceleration for the various quantities, P, f, G, c, which enter into the equation (V) for resultant acceleration.

The curves Q, R, are the curves of equivalent acceleration for the train resistance (f). These curves are plotted as follows: The value of f having been determined, for various speeds, either by means of some formula, or by reference to tabulated data or to curves obtained from actual tests, the " equivalent " acceleration corresponding to each value is calculated by the formula given in equation (21*a*); and each acceleration coefficient value is then plotted as an ordinate, using the speed value corresponding thereto as abscissa. The curve is then drawn through these points. In one of the curves (Q), the resistance values (f) used in computing the acceleration coefficients, included the friction of motor bearings and gearing, while in the other curve (R), this additional resistance was excluded. This explains the difference in ordinate values between the two curves. The first curve (Q) corresponds to cases when the car is moving by momentum only, at which times the mechanical resistance due to friction of motor bearing and gears must be overcome by the kinetic energy of the car. The second curve (R) corresponds to cases when motive power is being applied to the car. It is true that this resistance still consumes energy when the motors are furnishing power to the car, but since the curve of tractive effort (Fig. 5) represents the tractive effort which is available for *external work*, it follows that in determining the amount of gross traction per ton, (" P "), the friction of motor bearings and motor gearing is already eliminated. It is for this reason that two curves of equivalent acceleration due to train resistance are required, (Q, R),—one to be used in plotting acceleration curves, and the other to be used in plotting retardation curves.

The curves Q′, R′ are the same as the curves Q, R, but reproduced below the axis of x (with ordinates of negative sign).

(The train resistance values for speeds above 1 m.p.h. used in computing the coördinates of the curve R, agree substantially with the values obtainable for the train resistance of a single car by the formula of Mr. W. J. Davis, Jr. (see *Street Railway Journal*, Vol. XIX., May 3, 1902, p. 554). Between 0 m.p.h. and 1 m.p.h. the train resistance values used are such as to make allowance for the increase in train resistance when starting from rest. The curve, as drawn, indicates an initial starting resistance of about 18 lbs., per ton. For further information on this subject see paper on " Train Resistance " by J. A. F. Aspinall, M. I. C. E., read before the Institution of Civil Engineers, Nov. 26, 1901).

The curve M gives the equivalent acceleration values of the *gross traction* (P) of the particular motor equipment, whose time-function curves are to be examined. This curve is prepared substantially in the same manner as the curves Q, R, the values of P being determined by reference to the " corrected " motor characteristic curves, as already stated. The acceleration coefficients corresponding to the gross traction (per ton) obtainable at various speeds, are computed by equation (21a), and the values so obtained are plotted on the chart (curve M).

The curve N is what might be called a curve of " net " acceleration coefficients, obtained by subtracting the ordinate values of the train resistance coefficients (curve R) from the corresponding ordinate values of the gross traction coefficients (curve M).

The gravity factor, G, is, as we know, independent of the speed; consequently, the value obtained by equation 21a, for any given value of G, corresponding to any definite gradient, is constant at all speeds; the resultant curve will, therefore, be a straight line, parallel with the axis of x. In the chart, these lines have been drawn at the proper calculated ordinate distances corresponding and equivalent to all percentages of grades between 0.1% and 5%. These gradient percentage lines have been repeated below the axis of x, the two sets being thus suitable for up-grades and down-grades.

Since, as already seen, a grade of 1% represents a force of 20 lbs., it follows from equation (V), that the acceleration coefficient due to such a grade would be

$$= .01098 \times 20 = .22 \text{ m.p.h. per sec.}$$

It follows, therefore, that the scale of gradient percentages given at the right-hand end of the chart is such that the vertical distance, corresponding to each 1% of grade, is equal to 0.22

when measured on the scale of coefficients at the left-hand end of the chart.

The quantity c being also constant at all speeds, will also be represented by a straight line. The curves corresponding to this value are not shown on the chart.

The correction for curvature may, however, be made by reference to the gradient percentage lines, the effect of the track curvature being the same as an equivalent " up-grade." Since a 1% grade corresponds to 20 lbs. of tractive effort, the number of degrees of track curvature which is equivalent to a 1% grade will be

$$\frac{20}{b} = N \qquad \text{(XI)}$$

where N = the number of degrees of curvature.
and b = increased train resistance in lbs. per ton per degree of track curvature.

And the " equivalent grade percentage " would be:

$$G = \frac{N\,b}{20} = .05\,N\,b \qquad \text{(XII)}$$

As an illustration, let us assume an up-grade having an actual gradient of 2.672%, and a track curvature of 4° – 30′ (4.5°), and let b equal 0.9. The equivalent grade due to the curvature would be:

$$\frac{4.5 \times 0.9}{20} = 0.203\%$$

The effect under those conditions, would, therefore, be the same as if the total grade were:

$$= 2.672 + 0.203 = 2.875\%$$

In the case of a down-grade, the effect of course would be equal to the difference between these two values, or

$$-2.672 + 0.203 = -2.469\%$$

This net value which includes the allowance for both gradient and curvature is the value that would be used in plotting the curve by means of the Chart of Coefficients.

When b equals 0.8, we have, from equation (XI)

$$N = \frac{20}{0.8} = 25°$$

In this case the coefficient for each degree of curvature would, therefore, be 1/25, or 0.04, of the coefficient corresponding to a 1% grade. It follows, therefore, that two of the smaller spaces, each corresponding to a tenth of a 1% of grade, would represent the coefficient for 5° of track curvature.

When b equals some other number, the relation between the two kinds of coefficients is not so simple, for which reason the writer finds it preferable to make all corrections for track curvature by reference to equation (XII).

When there is no track curvature, the algebraical sum of acceleration coefficients includes only three coefficients, namely, those due to the gross traction, the train resistance and the grade. The curve N being already the algebraical sum of the first two, it follows that we have only to take either the *sum* or the *difference* in ordinate values, at any speed point, between the curve N and the horizontal line corresponding to any gradient, in order to obtain the corresponding resultant acceleration. This resultant acceleration coefficient is equal to the SUM of the ordinate values in the case of a DOWN-grade, and to their DIFFERENCE in the case of an UP-grade. Thus, on a down-grade of 1%, the resultant coefficient would be equal to the full vertical distance between the curve N and the "1%" line *below* the "zero" line (or axis of x), just as if the zero line itself had been displaced downward as far as the "1%" down-grade line. The effect of an up-grade would be exactly contrary, being the same as if the zero line had been displaced upward to the corresponding up-grade "percentage" line. The point at which the curve N crosses any gradient percentage line corresponding to an up-grade being, of course, the point at which the equivalent acceleration coefficients cancel each other and give a resultant acceleration equal to zero, it follows that this point is at the maximum speed that the particular motor equipment under consideration would give on that grade. If, instead of an up-grade, we examine the point of intersection of the curve N with a down-grade, we find, as is to be expected, that the maximum speed will be considerably higher. The chart may also be used to answer questions such as the following: On what down-grade, at any given speed, would the equivalent acceleration due to gravity be the same as that due to the train resistance? Also, on what grades would this force be sufficient to cause acceleration, and at what rate? The answer to this question is obtained very easily by taking the ordinate of the curve (Q), corresponding to any speed, and comparing it with the ordinate corresponding to any grade. When the two values are alike, there is no resultant acceleration. If one is greater than the other, there will be acceleration or retardation, according to the case. The chart thus answers at once, and in a very satisfactory manner, all questions in regard to the speed attainable under any desired set or aggregation of conditions. The Chart of Coefficients is, therefore, an instrument for quickly and accurately determining the answer to equations (28) and (*I*) under any kind of conditions, actual or hypothetical.

The train resistance coefficients, when once *properly* determined, will serve for any case. where the *train units* are of the same *kind* and *character*, it being now known that the train resistance values (" *f*," from which the curve R is derived), vary with the number of cars per train, and it being probable that they also vary according to the form and the size of car. It is evident that several different curves, analogous to the curve R and corresponding to train-units of different kinds, may be all plotted on the same chart of coefficients. The gradient percentage lines on the chart will, for obvious reasons, be the same for all cases whatsoever. Hence, we have only to plot the curve of gross traction coefficients (M) for any other motor, to be at once able to answer all questions about the speed and acceleration obtainable under any and all conditions. It is not well, however, to plot too many curves on the same chart, especially when they run closely together. It is more convenient, less confusing, and therefore preferable, to use a distinct chart for the " traction " curves (M and N), and for the " resistance " curves (" R ") corresponding to each kind of train-unit, or for not more than two distinct kinds of train-units.

It is desirable to plot the Chart of Coefficients with a rather large scale of ordinates. The scale of ordinates, in the original Chart of Coefficients, from which Fig.9 was made, is such that 1 m.p.h. per second equals 20 centimetres, so that the acceleration coefficient values may be easily read and plotted to the third decimal place. This accuracy is not so important for the portions of speed-time curves having a high rate of acceleration, but it becomes very important in the case of low accelerations, that is to say, in plotting the relatively flat portions of acceleration and retardation curves. In these portions, the acceleration coefficients have relatively small values, and consequently the percentage of error would be increased, unless these values can be read at least to the second, preferably to the third decimal place.

The greater ease and facility with which a chart can be used when plotted to a larger scale really simplifies the task of plotting the curves, and probably saves time in the end.

It is obviously desirable that the scale of *ordinates* be precisely the same in both charts, since otherwise it would be necessary to use proportional dividers or equivalent means of compensation for the difference in scales, in transferring the ordinate values from the Chart of Coefficients to the Chart of Reciprocals, in order to get the proper time increment values corresponding thereto. For this reason the two charts should be both made on the same kind of coördinate paper.

The charts shown in Figs. 9 and 10 have been reproduced with a view to making them suitable for practical use. For this reason they have been reproduced in sufficiently large size to permit accuracy in plotting or reading the coefficient values, and great care has been taken in the photo-engraving to have the scale of ordinates exactly the same in both charts

The Chart of Reciprocals (Fig. 10), serves for determining quickly the time increment value corresponding to any speed value. In this chart the ordinates represent acceleration coefficients exactly as in the Chart of Coefficients, and the abscissæ represent time values in seconds, on a scale sufficiently large to indicate small fractional values of seconds. On this chart are drawn various reciprocal curves. The curve A is the true reciprocal curve, being obtained by dividing 1 by *each* acceleration coefficient value and plotting the resulting value. The curve B is a curve obtained in the same way, by taking *half* the reciprocal value. In like manner, we obtain the curves C, D, E, F, corresponding, respectively, to the 4/10, 3/10, 2/10, 1/10 reciprocal values, and the curves G, H, I, corresponding, respectively, to twice, five times, and ten times, the reciprocal value.

This chart is so prepared as to take advantage of the relation shown in Appendix C in equation (*i*), where the acceleration coefficient enters, it will be noted, as a *reciprocal.* The manner of using it is very simple. The acceleration coefficient value for any speed having been determined by means of the Chart of Coefficients, it is transferred by dividers, or in any convenient way, to the Chart of Reciprocals, where it is used as an ordinate value and moved sideways, as such, until it intersects the *proper* reciprocal line. The " proper " reciprocal line depends upon the speed differences or increments, as the equations in Appendix C clearly show. Consequently, with speed increments of one mile per hour, curve A would be the proper curve; with speed increments of respectively, 1/10 m.p.h. and 10 m.p.h., the " proper " curves would be curves F and H. The smaller the speed increments, the more numerous will be the plotted points, and the greater the accuracy of the curve plotted. The process of determining, by means of these charts, the coördinate of a speed-time curve corresponding to any set of conditions, is so simple as compared with all previously known methods, that one can afford to use smaller speed increments and thus make the curve easier to draw and more accurate and satisfactory for any purpose.

It is important to note that the same reciprocal curve will not serve for all portions of a given speed-time curve, with equal accuracy, and that the reciprocal curves corresponding to relatively large speed increments (such as, for instance, curve I,) will be quite limited, both in application and in accuracy. This peculiarity, which is due to the form of the reciprocal curves, will be understood without difficulty, on glancing at the Chart of Reciprocals. It is seen that the higher acceleration coefficients (which correspond, as we know, to the more inclined portions of speed-time curves), have the short time-increment values, and that as the coefficient values become reduced (that is to say, as the speed-time curve " flattens "), the time increment values increase more and more rapidly. This relative increase in time increments continues until, for each reciprocal curve, in succession, beginning with curve I, which corresponds to the highest speed increments (Δy = 10 m.p.h.) and ending with curve F, which corresponds to the smallest speed increments ($\Delta y = 0.1$ m.p.h.) a point is finally reached at which the time-increment values obtained by reference to that particular curve would exceed the longest time value (9 seconds), which can be read on the chart. Thus, in the case of curve I, the chart limit would be reached when the acceleration coefficient became reduced to 1.11. This means that the curve I would be entirely useless for determining the time values of any speed-time curve or portion thereof not having an acceleration coefficient greater than 1.11. The chart limit for curve H would be, in like manner, an acceleration coefficient,

$$= \frac{5}{9} = 0.55$$

and the chart limit for any other curve would be

$$= \frac{\Delta y}{9}$$

where Δy = the speed increment corresponding to that particular curve. For example, in the case of curve A, where $\Delta y = 1$, the limit would be

$$\frac{\Delta y}{9} = \frac{1}{9} = 0.111$$

and for curve F where $\Delta y = 0.1$, the limit would be:

$$\frac{\Delta y}{9} = \frac{0.1}{9} = 0.011$$

These considerations clearly show that the reciprocal curves corresponding to the larger speed increments, such as curves G, H, I, can be used for determining the time-values only when plotting speed-time curves which have considerable slope or inclination (either upward or downward). It also becomes apparent that as the speed-time curve flattens, the reciprocal curves corresponding to smaller speed increments (such as B, C, D,etc.), become, first, desirable, then indispensable. For very accurate work the writer uses the curve A or the curve B for the highest accelerations (usually the curve A for coefficients above 2, and the curve B for coefficients between 1.5 and 2); and he uses, successively, the curves C, D, E, for intermediate lower coefficients, the curve F being used for the lowest coefficients. In cases when still greater accuracy is required than can be obtained with curve F, such as for plotting the nearly horizontal portions of speed-time curves (having coefficients approaching zero), the writer proceeds as follows: The net coefficient value, as obtained from the Chart of Coefficients by means of dividers or in other convenient manner, is increased twice, three times, or four times its value, and then used in the usual way for finding the time increment on the Chart of Reciprocals, by reference to curve F; the time value thus obtained is then divided by the multiplying factor used in enlarging the net coefficient, the result being the net time-increment value. A glance at the chart will readily show that this process is virtually the same as if a new reciprocal curve corresponding to smaller speed increments than the curve F were to be drawn. The method has the advantage over such a curve, however, that the coefficient is magnified, and that the time-increment reading is made at a point farther to the left, on the chart, where the reciprocal curves are farther apart, and where their inclination is greater, thereby enabling the reading to be made with much greater accuracy.

The five "observations" given at the end of appendix C, constitute rules which may be useful in selecting the proper reciprocal curves, for each particular case. Practical experience will, however, be the best guide.

Drifting Curves.—In the case of drifting curves, we have, as pointed out in equation (VII) to consider only the effects of the train resistance, track curvature and grades. The resultant acceleration coefficient at any speed is readily obtained from the Chart of Coefficients, just as in the case of acceleration curves. When the train is drifting and the energy required for turning the motors comes from the kinetic energy stored in the train, there is usually an increase in the train resistance due to the friction of the motor gears, etc., these motors being no longer electrically driven. The kinetic energy of the rotating parts, tends, in some measure, to counterbalance, or to neutralize, this increase. In case it is not fully neutralized, a new curve should be drawn, showing the acceleration coefficients corresponding to drifting and braking curves. The curve Q, as already stated, represents such a curve on the Chart of Coefficients. The values of the acceleration coefficient, as given on this curve, are the ones which should be taken in determining the resultant retardation graphically by means of this chart. The determination of the time increments is done in exactly the same manner as in the case of acceleration curves. Fig. 7 shows a set of nine drifting curves, including the drifting curve for a level and straight track, and eight curves, corresponding to up-grades and down-grades of, respectively, ½%, 1%, 1½% and 2%.

Braking Curves.—The coördinates of a braking curve should, in reality, be determined in substantially the same manner as the coördinates of acceleration and coasting curves. In order to do this, it would be necessary to draw on the Chart of Coefficients the curve of equivalent acceleration coefficients, corresponding to a given rate of braking. This curve would be almost, but not quite, a straight line parallel with the axis of x. The difficulty of this method is, that the form of brake lines varies so widely, and, at times, quite erratically. In practice, the process of plotting the braking curves is greatly simplified by making the assumption that the braking curve is a straight line. This is not exactly true, as already pointed out. In Fig. 3, the curve y, A, B, C is a true braking curve reproduced from an actual diagram obtained in the braking tests conducted by the New York Railroad Commission with various street-car brakes, in New York

City, in 1899. The dotted straight line, *y*, *a*, *b*, *c*, is the line enclosing the same area as the brake curve, this fact being clearly shown by the two distance curves o, *e*, *f*, *g* and o, *e'*, *f'*, *g'* on the lower part of the diagram. The first of these curves corresponds to the true brake curve, *y*, A, B, C, while the second corresponds to the equivalent brake curve, *y*, *a*, *b*, *c*. It will be seen that while the area enclosed by the two curves is exactly the same (being a trifle under .02 mile), the time required to cover this distance is greater in the case of the true brake curve than in the case of the modified one. In some cases, the time error resulting from the assumption of a constant rate of retardation, would be greater than in others, and might be serious. In most cases, however, it is negligible.

A closer approximation to the actual form of the brake curve can be made in the manner indicated in the right hand portion of Fig. 3, where the true brake curve *y*, *a*, *b*, *c*, and the straight line *y*, *a*, *b*, *c*, previously referred to, are both reproduced, together with the broken line, *y*, *b'*, *c*. It will be seen that this broken line constitutes a much closer approximation to the actual brake curve than the straight line, *y*, *a*, *b*, *c*. The acceleration coefficient of the straight line is found by calculation to be, approximately, 1.84. The broken line has an acceleration coefficient of about 2.31 in the upper portion, and 1.2 in the lower portion. The two portions of the broken line, *y*, *b'* and *b' c*, correspond to equal "drops" or reductions of speed. It is seen that the acceleration coefficient (which, in this case, might better be called retardation coefficient), is about 25% greater, for the upper portion (*y*, *b'*), while the retardation coefficient of the lower portion (*b' c*), is nearly 40% less than the acceleration coefficient of the straight braking line, *y*, *a*, *b*, *c*. By sub-dividing the brake curve into three portions,the broken line,now consisting of three portions, would enable a still greater degree of approximation to the true curve to be obtained, as will be readily understood. Unfortunately, owing to the erratic variations in the form of the curve itself, it would be more difficult to assign proper values to the retardation coefficients of the different portions in terms of the retardation coefficient of the straight braking line (*y*, *a*, *b*, *c*), corresponding to the same distance. For this reason, the writer does not recommend sub-dividing the brake curve into more than two portions, and does not even recommend this except where extreme accuracy is desired.

The assumption that the braking curve is a straight line greatly simplifies the process of plotting. The determination of the speed and time values, by which the line of braking may be drawn, comes under three general cases, constituting braking problems, which are treated and discussed as such in Appendix D.

It will be evident, of course, that the slope of the brake curve will still vary, even though the rate of retardation, due to the friction of the brake shoes, be assumed to be constant. This is apparent from equation (IX), in which it is seen that four factors (B, f, c, G,) enter into the equation for the retardation coefficient in braking. Owing, however, to the very fact that there is so much variation and uncertainty in the form of the brake curve, it is usual to make the assumption that a braking force of 150 lbs. per ton covers all three of the factors, B, f and c, for high-speed service. Hence, the only other force usually considered is the force of gravity (G). This, as we have already seen in Section I, enables equation (IX) to be simplified practically to the form shown in equation (X). The reason why the factor G is still retained and considered separately, is that the effect of gravity may be considerable on grades of relatively high percentage, and also that the effect would be opposite on up-grades and down-grades, respectively. In the case of the factors f and c, on the other hand, the effect is relatively small and always has the same sign. The force of gravity (G) being positive on down-grades will have the effect of neutralizing a part of the braking force applied. Thus, on a down-grade of 1 per cent., which corresponds, as already seen, to a tractive effort of 20 lbs., and taking, according to the usual practice, as stated above,

$$B—f—c=150$$

the net braking effort would be

$$150—20=130 \text{ lbs.}$$

and the coefficient, which, in this case, might properly be called retardation coefficient, would be, according to equation (IV),

$$=.01098\times 130=1.43$$

In the case of an up-grade of 1 per cent., the retardation coefficient would be equivalent to

$$=.01098\,(150+20)\;=1.87$$

The value of k used in the equations given in Appendix D is understood to be, in every case, that which corresponds to the resultant or net retardation, and it is determined in the manner just indicated.

It is seen that the foregoing method of plotting the braking curve still involves certain assumptions, which, in the present state of our knowledge, are unfortunately unavoidable. It is very much to be hoped that further experiments will be made for the purpose of determining the form of the true braking curve under various conditions of braking. It is also to be hoped that some convenient and practical means of analytical expression or of graphical representation of an *average* or *typical* braking curve may be arrived at. It is only then that it will be possible to eliminate the assumptions which now have to be made, and to attain a higher degree of precision in the plotting of the braking curve.

Distance-Time Curve.—Attention was called in Appendix A, in connection with equation (*e*), to the fact that the area of any portion of the speed-time curve comprised between two given intervals of time corresponds and is equal to the distance traversed by the moving body during that time. By taking advantage of this fact it is possible to plot on the same diagram on which the speed-time curve itself is drawn, another curve, the distance-time curve, usually called the "distance" curve. Such distance curves are shown in Figs, 1 to 4, inclusive. The coördinates for this curve are obtained, in each case, by integrating, successively, small strips of the area enclosed by the speed-time curve. This integration is usually done in practice by means of a planimeter or other integrating instrument. If, for example, we first integrate the portion corresponding to the first 20 seconds, the result obtained by the integration may be made a measure of the distance which the car will have traversed within the first 20 seconds. If, as pointed out in Appendix D, the numerical "area" result of the integration is divided by 3,600 (the number of seconds in one hour) the resulting figure will be the distance expressed in miles. Integrating, in like manner, the area comprised between 20 and 30 seconds we obtain the distance traversed in the interval of time comprised between the twentieth and thirtieth second. By integrating successively all the other portions of the speed-time curve between definite time limits in the same manner, other corresponding distance values (s) will be obtained. The total distance traversed will evidently be equal to the aggregate sum of all the separate distance values thus obtained. This total distance will be the highest point of the distance curve.

The object of integrating the area enclosed by the speed-time curve in separate strips, or "by parts," is, of course, to obtain the coördinates for various intermediate points on the curve, for the purpose of plotting the same. In plotting out the distance curve, the distance corresponding to the inferior time limit of integration (in equation [c], Appendix A) is equal to the so-called "constant of integration." Thus, in Fig. 4, in plotting the distance curve, *o-a-c-e*, between the points *a* and *c*, the distance value (*a*) obtained, as indicated in equation (*c*), by the integration of the acceleration curve from the beginning to the point *b*, would be equal to the constant of integration, which, in the case shown, is

$$a = \text{one mile},$$

and this value would have to be added to the distance value obtained by the integration of the portion of curve comprised between the points *b* and *d*, in order to give the total ordinate value or the actual location of the distance curve corresponding to the point *c*—that is to say, the ordinate at the upper limit of integration. This is evident, for, if the distance value obtained by integrating the area comprised between the points *b* and *d*, were to be plotted by measuring off from the axis of *x*, instead of from some point (*a*) higher up, it would then serve to indicate only the increase of distance covered between the points *b* and *d*. The addition of a distance value (*a*) equal to the distance already covered up to the point *b*, is necessary to bring the corresponding portion of the distance curve comprised between the points *b* and *d* into its proper place (*c*).

It is evident that the smaller the strips of area which are integrated at a time, and the more accurate the method of integration used, the more numerous will be the plotting points and the greater will be the accuracy with which the distance curve can be plotted. In the diagrams Figs. 1 to 4, inclusive, the distance curves are plotted so as to represent distances in miles, according to a scale of miles which is shown at the right-hand end of the diagram in each case. The process of computing the total area enclosed by the speed-time curve in very small portions is somewhat tedious. The work may be greatly simplified by the use of an instrument called the integraph, which was once exhibited, in 1888, before this INSTITUTE, by its learned inventor, the late Mr. B. Abdank-Abakanowicz. This instrument is an integrating instrument which, in addition to giving the numerical result of the integration, actually shows the steps of integration graphically, by drawing the so-called "integral" line. It is made in two sizes by Mr. G. Coradi, of Zurich, Switzerland, the distinguished maker of integrating instruments known by his name. The instrument admits of some range of adjustment, whereby the scale of ordinates may be varied. It is evident, however, that by means of proportional dividers, or by other well-known drafting-room methods, the scale of ordinates may be enlarged or reduced, so as to make it suitable for any scale desired for plotting the curve. The writer has made considerable use of the integraph during the last two years, and has found it exceedingly useful and convenient, not only on account of its precision but also as a time-saving device, in work of this character.

The distance-curve is of great utility in the plotting of the run-curves, because it constitutes the most practical means of determining the proper time points corresponding to a given distance. This is exemplified by means of the simple run-curve shown in Fig. 4. In plotting this run-curve it was desired to let the first or accelerating portion (which, as previously stated, was taken from Fig. 1), continue until a distance of exactly one mile had been covered. The dotted line *b-a* in Fig. 1, which intersects the distance-curve at a point (*a*) equal to a distance of one mile on the right-hand or "distance" scale, therefore represents the point at which the acceleration portion terminates. The drifting portion (*B*) of the curve in Fig. 4, was obtained by means of Fig. 2, beginning at a point (*b*) representing exactly the same speed as the point (*b*) in Fig. 1. The line *b-a* in Fig. 2 intersects the distance-curve at the point *a*. It being desired to let the drifting portion (*B*) of the run-curve also represent the same total distance traversed, exactly one mile, this curve was cut off in Fig. 2 at the point (*d*), so located that the last ordinate would intersect the distance-curve, in Fig. 2, at a point (*c*) whose vertical distance (*c*, *c'*) above the starting point (*a*) was equal to one mile, when measured on the distance scale. The portion of the distance-curve in Fig. 2, comprised between the points *a* and *c*, could, therefore, be reproduced in Fig. 4, starting from the point *a*. It is seen that the point *c*, in Fig. 4, corresponds to a distance of exactly two miles on the distance-scale. The distance-curve constitutes a convenient means, and the most practical means, whereby the various kinds of curves may be cut off and connected at the proper points in assembling them together to form the run-curves. This will be further exemplified hereinafter in discussing the plotting of a service run-curve, constituting a practical illustration of the process of plotting such curves.

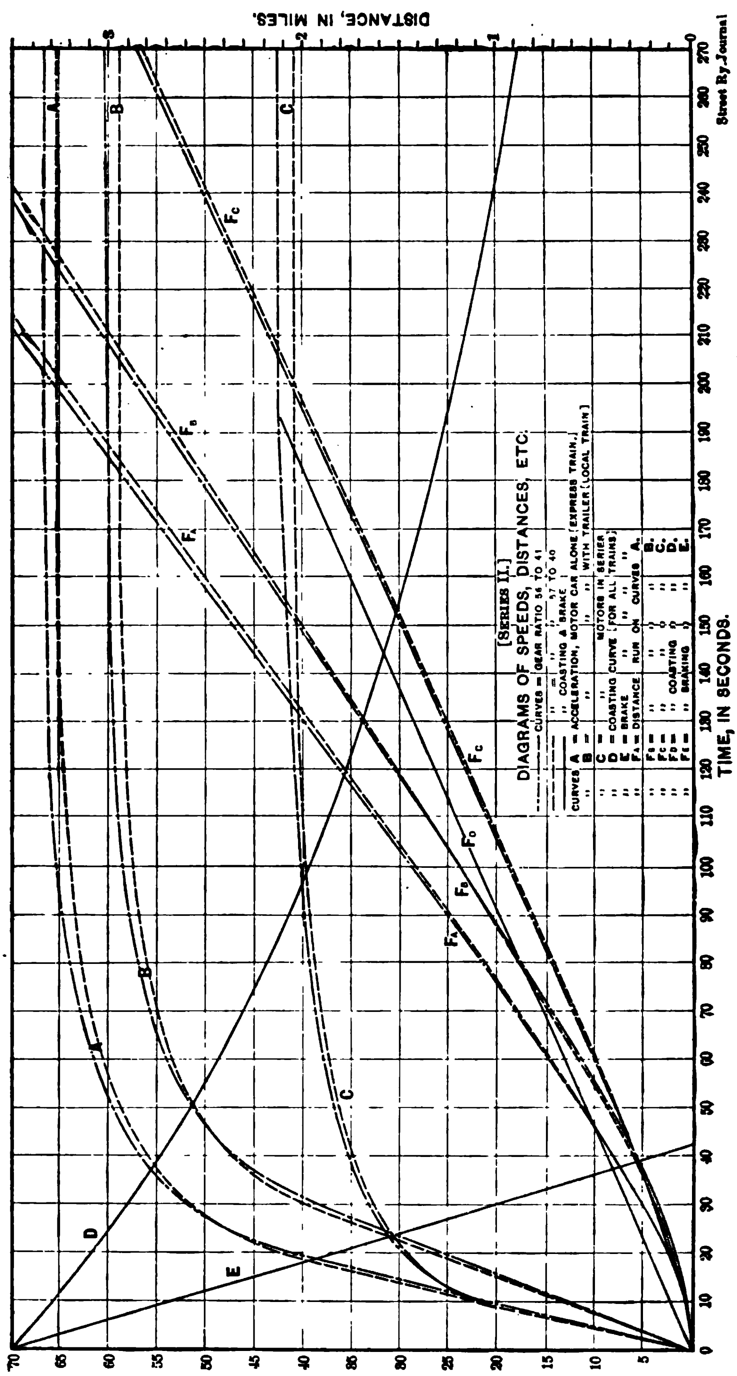

DISTANCE, IN MILES.
[SERIES II.]
DIAGRAMS OF SPEEDS, DISTANCES, ETC.
CURVES = GEAR RATIO 56 TO 41
" " " 57 TO 40
" COASTING & BRAKE
CURVES A = ACCELERATION, MOTOR CAR ALONE (EXPRESS TRAIN.)
" B = " " " WITH TRAILER (LOCAL TRAIN)
" C = " MOTORS IN SERIES
" D = COASTING CURVE (FOR ALL TRAINS)
" E = BRAKE " " "
" F_A = DISTANCE RUN ON CURVES A.
SPEED (IN MILES PER HOUR.)
TIME, IN SECONDS.
Street Ry. Journal

FIG. 11.

From the above it will be seen that the speed-time curve establishes a relation between the distance, speed, and the time, in any given case. Hence, if any two of these three quantities are given or assumed the third can be determined. In the majority of cases the distance is known, at least approximately. The quantities to be determined by means of speed-time curves are either the speed to be obtained, when the time is assumed or known, or else the time required for a given service, when the speed is known or assumed.

Modified Curves.—Fig. 11 is reproduced for the purpose of illustrating the modifications produced in the acceleration curve and the distance-curve by various changes in service conditions. The lower "*A*" curve is the same as the solid line curve in Fig. 7. The lower "*B*" curve shows the change in the form of the acceleration curve produced by the addition of a trailer-car to the motor car. It bears a relation to the curve *A* similar to that of a curve for an up-grade of relatively high percentage, this relation being obvious from the analytical principles previously set forth. The lower curve, *C*, shows the acceleration which would be obtained if the motors remained connected in series throughout the acceleration cycle. The curves *Fa*, *Fb*, *Fc*, etc., are the corresponding distance-curves. In the case of both acceleration and distance-curves the upper line of each pair is that which corresponds to the next higher gearing ratio. It should be noted that while the maximum speed attainable is higher with an increased gearing ratio, yet the initial acceleration is smaller. The two acceleration curves of each "pair," and the two corresponding distance curves, cross, in the figure, at a point near the bend or "knee" in the curve. This characteristic feature of the two curves is the reason why the higher gearing ratio would be selected when the lengths of run are relatively great, whereas the lower gearing ratio would be selected when the lengths of run and the time allowable for acceleration are relatively short.

Run-Curves.—The process of plotting a run-curve consists in selecting and in bringing together properly, certain determinate portions of acceleration curves, drifting curves and braking curves, constituting its component parts.

The operation of selecting and plotting the portions of component curves aforesaid, naturally involves a more or less comprehensive study of all the basic data, the peculiar features and the specific conditions of the case, as well as the determination of their influence and effects by reference to the principles of analysis and synthesis previously considered; and it also requires the practical application of methods of plotting such as hereinbefore described. The operation of bringing together and of combining the component curves, involves the utilization of the distance-time curve as a gage of the distance and time intervals corresponding to each distinct portion of curve; and it requires some knowledge of drafting room methods.

In a conventional run-curve of the simplest form, such as shown in Fig. 4, there are only three component parts (*A*. *B*, *C*), which are easily combined together in the manner already explained in Section 1. Such a run-curve, however, only applies when the track actually is, or is assumed to be, straight and level. When it is desired to make proper allowance for track curves and grades, the process of producing the run-curve is no longer as simple.

Fig. 12 shows a "service" run-curve in which the speed line is modified by grades only. It represents express service run No. 7, running north, on the New York & Port Chester Railroad.

Fig. 13 shows a "service" run-curve in which the speed line is modified both by grades and track curves. It represents express service run No. 11, running south, on the same line.

The latter curve has been specially selected as an interesting practical example of speed-time curve plotting, embodying substantially all the features and complications which are usually met with in the plotting of such curves.

These two service-run curves form part of a large series of such curves prepared for the aforesaid company during the last year, under the joint direction of Mr. W. C. Gotshall, president of the company, and the writer, to serve as the basis and also as the corroboration of technical evidence regarding the engineering features and merits of the project of the company, as presented in the hearing before the New York State Railroad Commission; and they are here reproduced, together with some of the corresponding subsidiary curves, by permission of Mr. Gotshall. The writer further takes this occasion to acknowledge many valuable ideas and suggestions kindly given by Mr. Gotshall, and gladly utilized in the preparation of this paper.

Tables I. and II. give the line data which are the basic data by reference to which these two run-curves were prepared. These data were taken or calculated from the profile maps, location maps and field notes of the preliminary surveys made of the entire line. The first column gives the reference letters by means of

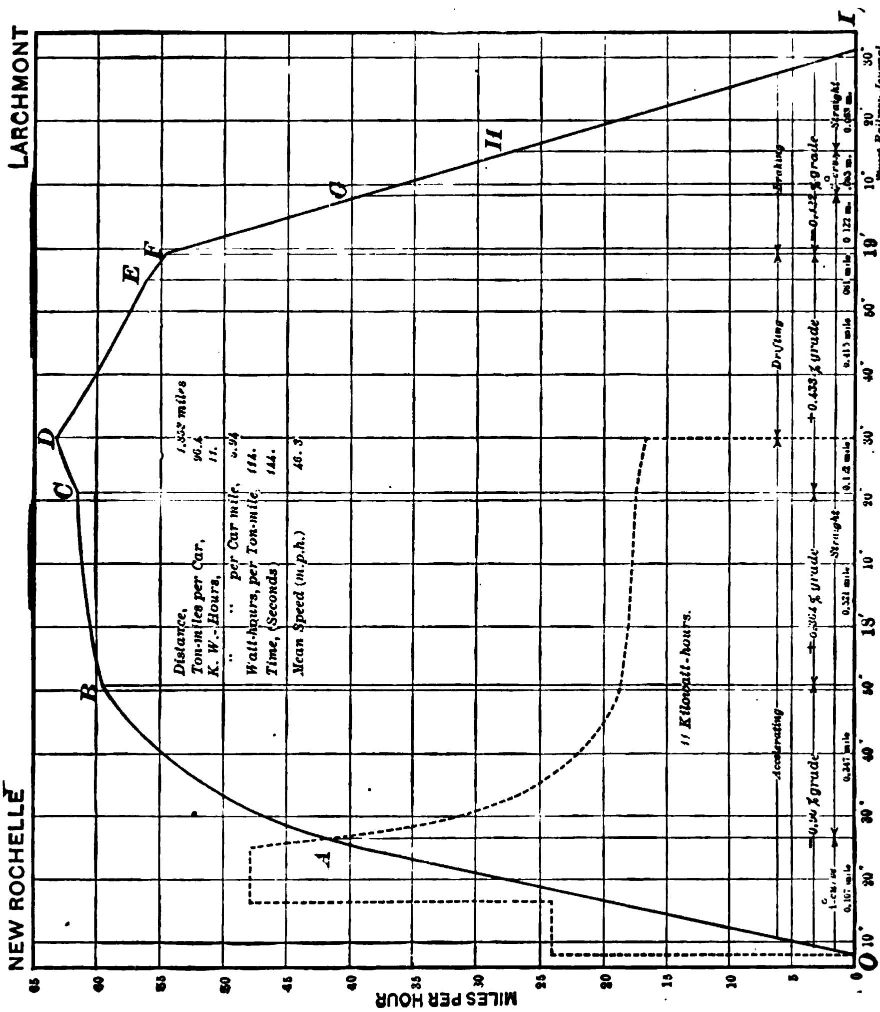

LARCHMONT
NEW ROCHELLE
MILES PER HOUR
Distance,
Ton-miles per Car,
K. W.-Hours,
Watt-hours, per Ton-mile,
Time, (Seconds)
Mean Speed (m.p.h.)
11 Kilowatt-hours.
Accelerating
Drifting
Braking
Street Railway Journal

FIG. 12.

which the corresponding portion of the run-curve in the figure may be identified. Column II. gives the lengths of the corresponding portions of the total run in fractions of a mile. Columns III. and IV. give the percentages of up-grade and down-grade, respectively. Column V. gives the track curvature, stated in track " degrees," the word " tangent " being synonymous with " zero degrees " (0°), and being used to designate *straight* portions of track, all in accordance with the established practice in civil engineering. Column VI. gives the track curvature ex-

Table I.—Line Data for Express Service Run No 7 (North) New York & Port Chester Railroad Co.

I.	II.	Per Cent. of Grade		Track Curvature		
Portion No (Fig. 12)	Length Miles	III. Up	IV Down	V Degrees	VI * Equival't Grade %	VII. Net Equivalent Grade
0 to A	.107	....	0.900	4°	—0.180	—0.720%
A to B	.347	....	0.900	Tangent	......	—0.900%
B to C	.521	0.364	....	"	......	−0.364%
C to E	.567	....	0.433	"	......	—0.433%
E to G	.183	0.122	....	"	......	−0.122%
G to H	.065	0.122	....	2°	+0.090	−0.212%
H to I	.063	0.122	....	Tangent	......	+0.122%
	1.853	....	....	......	......	......

Table II.—Line Data for Express Service Run No. 11 (South) New York & Port Chester Railroad Co.

I.	II	Per Cent. of Grade		Track Curvature		
Portion No. (Fig. 13)	Length (Miles)	III Up	IV Down	V	VI * Equival't Grade %	VII Net Equivalent Grade
0 to A	.306	0.283	....	Tangent	......	+0.283%
A to B	.113	0.283	....	1° 30′	+ .068	+0.351%
B to E	.374	0.283	....	Tangent	......	+0.283%
E to H	.208	0.283	....	7° 10′	+0.323	+0.606%
H to I	.135	0.283	....	Tangent	......	+0.283%
I to J	.189	Level	....	"	......	......
J to M	.189	1.300	....	"	......	+1.300%
M to N	.111	Level	....	"	......	......
	1.625	....	....	......	......	......

*By equation (XII), taking b = 0.9

pressed in equivalent percentage of grade. In Column VII. the " net equivalent grade " values are given, these values being the same as the grade values given in Column III., for all portions on which there are no track curves, and being equal to the algebraical sum of the values given in Columns III. and VI. for all portions of the run on which track curves occur.

It will be noted that in the tables the total length of run is subdivided into as many portions as there are changes in track gradient or in track curvature. each portion being tabulated separately in a distinct line. Each of the lines in the tables corresponds to at least one " component " portion of the run curve Some of them may correspond, as will be seen later, to two or more such component portions. Thus, while the total distance for run No. 7, amounting to 1.853 miles, in Table I., is sub-divided into seven distinct portions, each tabulated in a distinct line, it will be found that the corresponding run-curve (Fig. 12) is made up of nine " component " portions of run. In like manner the eight distinct portions of the run (No. 11) tabulated in Table II., correspond to fourteen " component " portions of run in Fig. 13.

The manner in which the aforesaid line " characteristics " influence the form of the speed-time curve has already been fully considered. In plotting a run-curve we need, it is obvious, to consider in addition to these line data, the other forces concerned in acceleration. If we use the " chart " method, previously described, we will need a " Chart of Coefficients," on which will be drawn the proper curves analogous to M and N, giving, respectively, the gross and net motor accelerations as functions of the speed, and also the curve R, giving the equivalent acceleration due to train resistance. The " corrected " speed curve and the tractive-effort curve marked " C " in Fig. 5, constitute the motor characteristics, by reference to which the curve of gross acceleration coefficients (M), shown in Fig. 9, was prepared. This curve (M) is substantially the same as was used in plotting the set of acceleration curves corresponding to various gradients, shown in Fig. 7, and the service-run curves, shown in Figs. 12 and 13.

It is proper to state that the straight portion of this curve M is based upon the assumption that the mean value of the current during the early stages of acceleration will be exactly 400 amps. per motor, corresponding to a maximum initial tractive effort of 2644 lbs. per motor, as indicated by the corrected curve of tractive efforts (C) in Fig. 5.

The track curves occurring during a given run are the first features requiring attention. If the track curves occur at the beginning or at the end of the run they usually impose no limitations on the speed. When they occur at midway points on the run they will impose limitations unless they are of relatively small degree. Run No. 11 furnishes an instance of this kind, as will be seen later.

Service Run No. 7.—(Fig. 12) begins with a portion, 0.107 mile

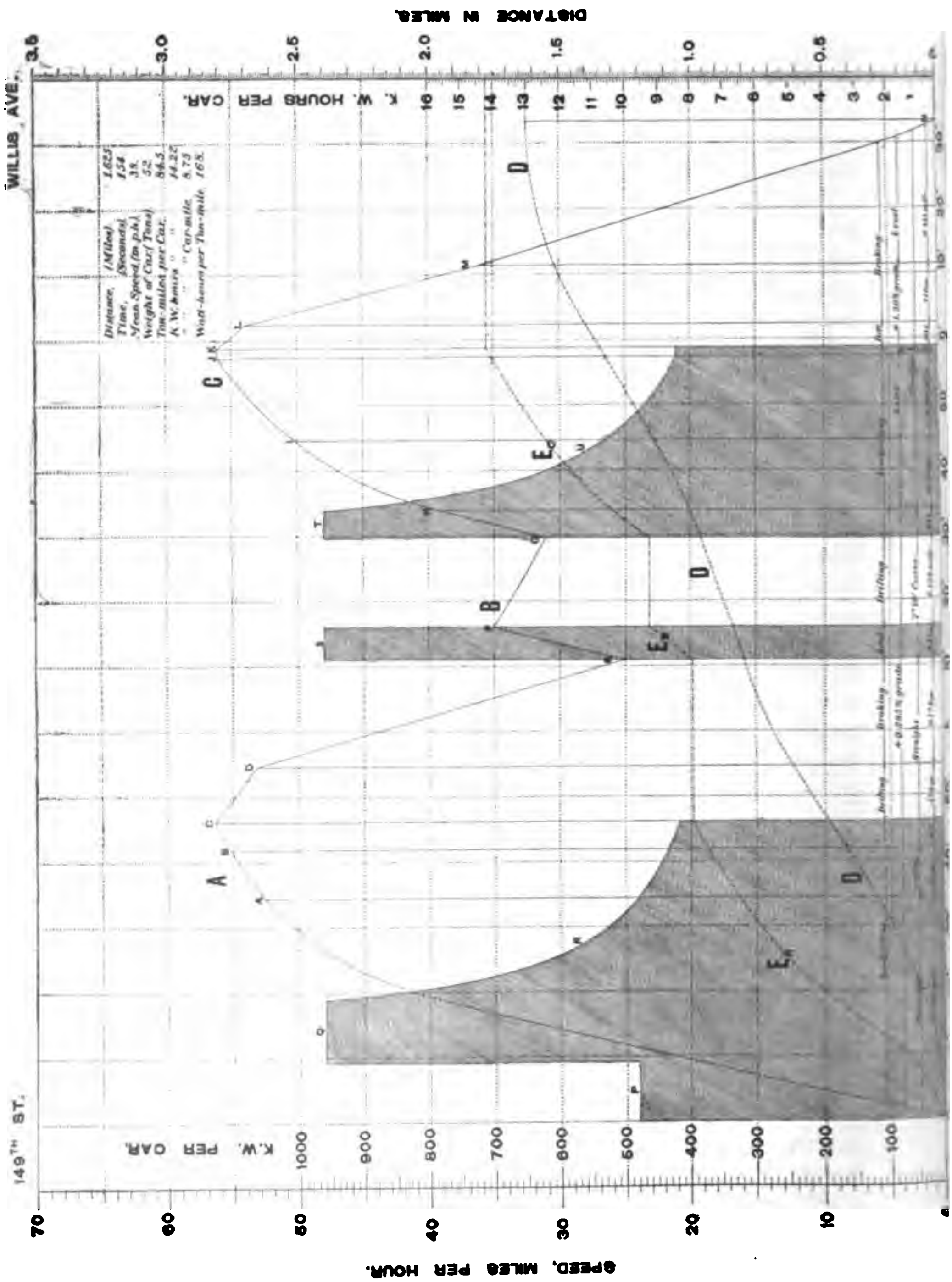

DISTANCE IN MILES.
K. W. HOURS PER CAR.
K.W. PER CAR.
SPEED, MILES PER HOUR.
WILLIS AVE.
149TH ST.
Distance, (Miles) 1.625
Time, (Seconds) 154.
Mean Speed (m.p.h.) 38.
Weight of Car (Tons) 52
Ton-miles per Car 84.5
K.W. hours " " 14.27
" " " Car-mile 8.75
Watt-hours per Ton-mile 168.

Fig. 13.

in length, having a track curve of 4 degs. and a down-grade of 0.90%. The data in Column VI, giving the "equivalent grade," and in Column VII, giving the "net grade," show that the advantage of the down-grade is partly offset by the increase in the train resistance due to the track curve, the resultant effect being the same as if the track were straight and had a down-grade of only 0.72% instead of 0.90%. The first portion (*O-A*) of the service-run curve in Fig. 12 will, therefore, be the same as the first portion of an acceleration curve, such as would be obtained on a straight track having a down-grade of 0.72%. The net acceleration coefficients for this portion of the curve may, it is obvious, be readily obtained from the "Chart of Coefficients" (Fig. 9), and the corresponding time values can then be obtained by reference to the "Chart of Reciprocals" (Fig. 10) in the manner already fully explained.

The process of determining the coördinate points for the portion of curve to be plotted has already been described fully in the previous pages, and, therefore, need not be detailed further. The coördinates of the curve having been determined and the curve itself having been plotted and drawn, the next step is to ascertain the exact point at which the first portion (*O-A*) terminates. This is done by means of the distance-curve, in the manner already fully explained, and also illustrated by reference to Fig. 4 in the foregoing reference to the "distance-time curve." The time point at which the ordinate of the distance-curve, when measured by the scale of distance, indicates a distance of 0.107 mile, represents the time point at which the first portion of the run-curve (*O-A*) should terminate. A vertical ordinate line is usually drawn from the terminal point *A* after it has been thus determined. The end of the first portion of the run (*A*) corresponds to a speed of 41.8 m.p.h.

The second portion of the run has, according to Table I., a length of 0.347 mile, with the same down-grade (– 0.90%) but without any curve. It begins at the speed point *A* (= 41.8 m.p.h.) and ends at the point *B* (= 59.6 m.p.h.), The coördinates for this portion of the curve are to be determined in substantially the same way as for the first portion of the curve, with the exception that the time values for all speed points higher than 41.8 m.p.h. are the only ones which need to be determined. After the curve has been plotted and drawn to a certain length, the point *B*, at which it should be cut off, is determined by reference to the corresponding distance-curve. The third portion of the curve, as shown in Table I., is 0.521 mile in length, straight and on an up-grade of 0.364%. The coördinates for this portion of the curve are determined and plotted, and the terminal point (C' = 61.7 m.p.h.) is determined in the same manner as before. The relative flatness of this portion of the curve is both the result and the indication of the effect of the up-grade, the relative gain in speed being, as should be expected, much less on an up-grade than on a down-grade.

As the three portions of run-curve thus far considered cover a little over one-half of the total distance, it becomes necessary, in proceeding to plot the next portion, to anticipate and to determine two things: First, the point at which the electric power is to be shut off and at which the train will begin to coast; and, second, the point at which the brakes will be applied. Both points are determined somewhat arbitrarily, and vary greatly in different cases. It may be said that both are related to, and depend upon, the time allowed for making the run, or, in other words, the schedule speed required. The sooner the electric power is shut off the smaller, it is obvious, will be the amount of electric energy consumed during the run. The effect of cutting off the electric power early is to increase the length of time during which the train must drift or coast, and also to lower the speed at which the brakes must be applied, in order to cover the same given total length of run. When economy is an important consideration it is obviously desirable that the amount of coasting should be greatly increased, and that the braking should begin at as low a speed as possible, for, the greater the amount of speed reduction obtained by drifting or coasting, and the lower the speed at which the brakes are applied, the smaller the momentum of the car at the time of braking, and, consequently, the smaller the amount of energy dissipated by friction during the operation of braking. When time is an important consideration, however, as in the case of a rapid transit or express line, it becomes necessary to sacrifice economy in order to gain time. In such cases we must shorten considerably the period of time during which the train will coast, and we must begin the operation of braking at a much higher speed. It may be desirable, in fact, to reduce the period of braking until it is virtually eliminated, the brakes being practically put on at the same instant that the power is shut off. A run-curve made under those conditions will be the curve corresponding to the *minimum time of run* for that particular case, although it will not be the curve of *minimum energy consumption*.

It is desirable, even when the quickest time is to be made, to still make allowance for a certain period of coasting between the time that the power is shut off and the time that the brakes are applied. This gives the motorman a certain margin, for, if running behind, he can keep the current on a little longer and reduce or eliminate, the period of coasting, while if running ahead, he can cut off the power earlier, and increase the period of coasting. In the service run under consideration (Fig. 12), the acceleration is continued on entering the fourth portion of the run (C to E), until the point D, distant 0.152 mile from the point C, has been attained. At the point D (= 63.3 m.p.h.) the current is shut off and the train begins to drift. In this particular case it was decided to let the coasting continue until the speed became reduced to 55 m.p.h., at which point (F) the operation of braking is to begin. The fixing of the braking point has the effect of also fixing the point D, at which the current is to be cut off. This is due to the fixed relation between the form of a speed-time curve and the area enclosed by it, and also to the fact that this area, as pointed out in Appendix A, is equal to. and serves to measure, the distance covered by the train in the corresponding time interval.

The fourth portion (C to E) of the run tabulated in Table I, will, therefore, correspond to two "component" curves, one being an acceleration curve (C-D), and the other a drifting curve (D-E). The acceleration curve is to be determined and to be plotted in the manner indicated for the preceding portions. As the point D is not known and has to be determined, it will be necessary to plot the curve to some arbitrary length, such as may be deemed sufficient for the purpose. If too long, the excess can be erased; if too short, it will have to be lengthened.

The point D, at which the drifting begins, cannot be determined until we ascertain how much distance will be covered by the train while braking from the speed of 55 m.p.h., which, as already stated, was fixed as the point at which the operation of braking is to begin. It will be necessary, therefore, to determine and even to plot out the braking curve before plotting the drifting curve itself.

In plotting the braking curve we have to work backwards, so to speak, for we must, of necessity, begin with the last portion. According to Table I, the last portion of the run is straight, on a + 0.122% grade, and it is .063 mile in length. We need to determine, first, the speed at which the train would be running at the time ot entering this portion; second, the time consumed in running through this portion. This case corresponds exactly with the first brake-curve problem discussed in Appendix D. The equations (*e*) and (*f*) therein obtained for the speed and time values will exactly apply in this case. The speed will be:

$$y = \sqrt{7200\,k\,s} \qquad (e)$$

and the time will be:

$$x = \frac{y}{k} = \frac{\sqrt{7200\,k\,s}}{k} \qquad (f)$$

in which

y = the initial braking speed for that portion of the run.
x = the time interval for that portion of the run.
k = the net or resultant retardation coefficient.
s = the length of the corresponding portion in miles.
= .063 mile, in this case.

The value of the retardation coefficient, k, when calculated by the formula given in equation (X), will be found in this case to be:

$$k = 1.647 + (0.01098 \times 0.122 \times 20) = 1.674$$

Substituting the proper values in equation (*e*) we have:

$$y = \sqrt{7200 \times 1.674 \times 0.63} = 27.6 \text{ m.p.h.}$$

(which is the speed at the point H); and the time, by equation (*f*),, will be:

$$x = \frac{27.6}{1.674} = 16.5 \text{ seconds.}$$

We next proceed to determine the coördinates for the portion of run ($G\,H$) immediately preceding the last portion.

The case corresponds exactly with Problem 2 in Appendix D. The initial speed (at the point G) will be

$$Y = \sqrt{7200\,k\,s + a^2} \qquad (l)$$

where

Y = the entering or initial speed.
a = the leaving or final speed.
s = the distance.
k = the net coefficient of retardation.

The final speed (a) will obviously be the same as the initial speed y (= 27.6 m.p.h.) for the last portion of the run.

The distance, from Table I, is

$$s = .065 \text{ mile.}$$

The net retardation coefficient for the "equivalent" grade given in Table I., Column VII., will, by equation (X), be

$$\begin{aligned} k &= 1.647 + (.212 \times 20 \times 0.01098) \\ &= 1.694 \end{aligned}$$

Substituting these values in equation (l) we will have:

$$\begin{aligned} Y &= \sqrt{7200 \times 1.694 \times .065 + 759.3} \\ &= \sqrt{792.7 + 759.3} = 39.4 \text{ m.p.h.} \end{aligned}$$

(which is the speed at the point G).

The time interval corresponding to this portion of the run will be:

$$x = \frac{Y - a}{k} \qquad (i)$$

$$= \frac{39.4 - 27.6}{1.694} = 6.97 \text{ seconds}$$

or practically 7 seconds.

The speed at the point G being only 39.4 m.p.h., as already seen, it follows that the braking must have begun before the train enters upon the portion $G\ H$. The next step, therefore, is to determine how much of the portion ($E\ G$) preceding the portion $G\ H$ will be covered by a train when braking a long enough time to reduce the speed from 55 m.p.h. to 39.4 m.p.h. This case corresponds exactly with problem 3 in Appendix D. The formula for the distance traveled is

$$s = \frac{Y^2 - a^2}{7200\ k} \qquad (m)$$

where

Y = the initial braking speed.
a = the final braking speed.
k = the net retardation coefficient.
s = the distance traveled while braking from speed "Y" to speed "a."

The net equivalent grade (Column VII.) being the same for this portion as for the last portion ($H\ I$), the net retardation coefficient will also be the same, or $k = 1.674$.

Substituting values in equation (m) we have:

$$s = \frac{55^2 - 39.4^2}{7200 \times 1.674} = .122 \text{ mile}$$

which is the length of that part of the portion of run $E\ G$.

This, as we find from Table I., is not the whole of the portion of run $E\ G$, which is 0.183 mile long. The difference, which is

$$0.183 - 0.122 = 0.061 \text{ mile,}$$

represents distance covered by the train *before* the braking begins, or, in other words, while the train is still drifting. Hence the portion of run $E\ G$ must be represented in the run-curve by two " component " curves, one ($E\ F$) being a drifting curve and the other ($F\ G$) being a braking curve. The time interval corresponding to the portion $F\ G$ is calculated in the same manner as for the portion $G\ H$ by means of formula (i). Its value is

$$x = \frac{55-39.4}{1.674} = 9.3 \text{ seconds}$$

The next step is to plot a portion of the drifting curve from which the portion $E\ F$ may be cut off. This can be done by the chart method, using the curve Q on the chart of coefficients. We may begin plotting from a slightly higher speed, say 57 m.p.h. or 58 m.p.h., and plot the curve downward with positively increasing time values, in the usual way, until the speed line comes down to 55 m.p.h.—where the drifting ceases.

We may, however, plot the drifting curve in the opposite direction or " backward " as it were, starting from the lower speed limit (55 m.p.h.), and continuing upward and backward until the length of the portion plotted is sufficient to represent a little more than the distance required to be covered. With a little practice, it is as easy, by the chart method to plot a curve " backward," as it is to plot it " forward." This is one of the incidental features and advantages of the method. The *modus operandi* when plotting backward is, in reality, exactly the same, but the *order* is reversed. In plotting a drifting curve " forward," the retardation coefficient values would be taken from the chart of coefficients in the order of *descending* speed values, or from right to left, and the summated values would be reckoned and plotted in the right-hand direction, like positive abscissæ. In plotting " backward," we merely reverse this order; the retardation coefficients are taken from the chart of coefficients in the order of *ascending* speed values, and the summated time values are to be reckoned and plotted in the left-hand direction, as if they were negative abscissæ.

The curve having been plotted (on a separate sheet) the next step is to determine the " entering " point (E), at which it should be cut off. This is to be done, as in the case of the three portions of acceleration curve (O to C), by reference to the distance curve corresponding to this drifting curve. The initial or entering speed (at the point E) is found to be 56.4 m.p.h.

We now come to the final and somewhat difficult operation of making the " joint" or connection between what might be termed the " acceleration end " and the " retardation end " of the run-curve. This joint occurs, as already seen, at a point D, on the portion $C\ E$. which point is, itself, to be located. It is necessary in this case to operate from both ends of the portion of run $C\ E$. For this purpose we need an acceleration curve suitable for the beginning of this portion, and a drifting curve suitable for the end thereof. Suppose we plot, in accordance with the data given in Table I., for the portion $C\ E$, on separate sheets of tracing paper or of tracing cloth, two distinct speed-time curves—one being an *acceleration* curve whose " beginning " or lowest speed point is the same as the speed at the point C (= 59.6 m.p.h.)—the other being a *drifting* curve, whose " end " or lowest speed point is the same as the speed at the point E (= 56.4 m.p.h.); and suppose the distance curve for each speed-time curve to be also drawn on the same sheet therewith. If the two sheets be placed in correct ordinate relation with a straight line serving as the axis of x for both curves, the acceleration curve being placed at the left and the drifting curve at the right, and if they be then moved toward each other until they become partially superposed, the upper ends of the two curves will eventually come in contact; and if the sheets continue to move toward each other, the point of intersection between the two speed-time curves will gradually become lower, until it corresponds exactly with the right speed point D, at which point the motion should stop. When the two curves are in this relation, they will precisely represent the portion of the run $C\ D\ E$ shown in Fig. 12,and it will be found by reference to the distance-curves, that the aggregate distance corresponding to the two component curves $C\ D$ and $D\ E$ will be exactly 0.567 mile, as given in Table I. It is evident that if the curves were made to intersect at a point higher than the point D, the aggregate area, and, consequently, the aggregate distance covered by the two curves would be greater, whereas, if the curves were moved closer together, thereby bringing the point of intersection below the point D, the area enclosed, and, consequently, the distance covered would be smaller. The point D is, therefore, the only one which meets the condition. It will be found that the acceleration portion, *C. D*, ends when a speed of 63.3 m.p.h. has been attained and a distance of 0.152 mile has been covered, the rest of the distance (0.415 mile), being covered while drifting from this speed to the entering speed at the point *E* (56.4 m.p.h.).

The component curves *C D* and *D E* having been determined, they can now be plotted on the same sheet as the preceding portions of the run-curve. The portion *E F*, plotted on a separate sheet, may now be transferred to the same sheet. The portions of braking curve, *F G*, *G H* and *H I*, being straight lines, can be readily plotted by reference to the data calculated in the manner previously indicated. Thus, the point *G* corresponds to a speed of 39.4 m.p.h. and a time distance of 9.3 seconds from the ordinate of the point *F*. In like manner, the point *H* corresponds to a speed of 27.6 m.p.h., and a time distance of 7 seconds from the ordinate of the point *G*. The terminal point *I* occurs at a time distance of 16.5 seconds from the ordinate of the point *H*.

Service Run No. 11 (*Fig.* 13).—A glance at the curve shows that it has two " notches " and three "crests."*A*, *B*, *C*, indicating three distinctive acceleration cycles. The acceleration in the first cycle lasts from the time of starting until the speed point *C* (56.35 m.p.h.) is attained, after which the train drifts as far as the point *D* (53.2 m.p.h.), and then brakes as far as the point *E* (25 m.p.h.), where the second cycle begins. The acceleration in the second cycle continues until the speed has risen to the point *F* (35 m.p.h.), after which the train drifts to the speed point *G* (31.1 m.p.h.), where the third cycle begins, with acceleration continued to the speed point *K* (56.2 m.p.h.), followed by drifting to the point *L* (54 m.p.h.), at which point the final braking begins, being continued to the end of the run (*N*).

The striking difference in outline between this run-curve and the run-curve shown in Fig. 12, is due to the restriction imposed upon the speed by a track curve of relatively short radius (7° 10′), which occurs in the portion *E H*, about midway in this particular run. It will be found by reference to the line data in Table II., that there are two track curves in this run. The first track curve (1° 30′) occurring in the portion *A B* and tabulated in the second line in Table II., does not impose any limitations on the speed, such track curves being considered safe at any speeds below 60 m.p.h. In the case of the second track curve (7° 10′), however, it is necessary to restrict the speed considerably. It was decided in this special case that the speed on entering this particular track curve ought not to exceed 25 m.p.h., and that the speed ought not to exceed 35 m.p.h. while running on the curve, excepting toward the end, where it would be allowable to permit the speed to rise as high as 40 m.p.h. while running out of the track curve. This restriction, it will be readily seen, accounts for the notch at the point E, as well as for the crests B C, in the run-curve. This case is an interesting illustration of the important modifying effect produced on the service run-curve by a track curve of relatively small radius occurring at a midway point in the run. The track curve is, in this case, the primary cause for the two supplemental accelerations required in this particular service run, each of which involves an application of electrical energy to the train, and, consequently, occasions a material increase in the energy consumption required for the run, as will be found later, on plotting the power input curves.

When the service run has but a single cycle, as in Fig. 12, the plotting must of necessity begin with the very first portion. When it has several acceleration cycles, as in this case, if the speed value at the beginning of the second or third cycle is determined, or arbitrarily fixed, it is possible to begin the process of plotting at one of these cycles. Thus, in this particular case, the speed being restricted and set to 25 m.p.h. at the point E, corresponding to the point at which the train enters the sharp track curve, it would be possible to begin the process of plotting the run-curve from the point E instead of from the point O. Advantage may be taken of this fact when it is desired to do work quickly, and to apportion it among as many persons as possible. In this case we shall follow the usual practice and assume that the curve is to be plotted by beginning at the very first portion (O A).

The operation of plotting the run-curves is susceptible of being still further simplified, especially when the run-curves are plotted and drawn on a relatively large scale, by a " method of interpolation," which the writer has used considerably, with success and satisfaction. The method is specially useful when the number of run-curves to be made is large. For the purpose of giving an example illustrating the nature and practical use of the method, it will be assumed to be the method used in plotting the service run-curve shown in Fig. 13.

The *Interpolation Method* is one in which the " component" curves are obtained by the modification of certain " fixed " reference curves. The method requires a " Chart of Accelerations," such as shown in Fig. 7, and a "Chart of Retardations," such as shown in Fig. 8. Each chart should contain various speed-time curves corresponding to several up-grades, to zero grade (level track), and to several down-grades, together with the distance-time curve corresponding to each speed-time curve. The curves in Figs. 7 and 8 correspond, as already stated, to "zero" grade, and to 0.5%, 1%, 1.5% and 2% of both up-grade and down-grade, the down-grade curves being *above* and the up-grade curves *below* the curve for level track, in both cases. The speed-time curves in both charts can be readily and quickly plotted by the "chart method" hereinbefore described. Where greater refinement is desired, the curves may be plotted for every fifth of a per cent. instead of every half per cent. of grade. The distance curves are plotted from coördinates obtained by the integration of the corresponding speed-time curve by the planimeter or by the integraph, in the manner already explained. The scales of speed and time values used on these charts should, for obvious reasons, be exactly the same as those used in the run-curves.

It may be interesting to note the fact that the acceleration curves in Fig. 7 have all been plotted on the assumption that the curve N on the Chart of Coefficients (Fig. 9) begins at the point a instead of the point b. This means that no allowance has been made in the curves for the increase in train resistance due to static friction at the time of starting. Theoretically, the dip in the curve N at the point b should cause a short bend convex to the axis of x in each acceleration curve, such that a line tangent to the straight portions would not pass through the origin of x but through some point to the right of it. It will be doubtless interesting and perhaps reassuring to learn that, practically, the error resulting from the assumption aforesaid is less than one-twentieth of a second, and is consequently negligible even when the time values a and b have been determined by the curve of reciprocals giving the greatest accuracy (F in Fig. 10), and further, that the discrepancy in time values practically vanishes when using reciprocal curves corresponding to speed increments of 0.5 m.p.h. or 1.0 m.p.h. (curves B and A).

Fig. 14 gives an enlargement of the portion of Fig. 7, containing the speed-time curves comprised between the speeds of 45 m.p.h. and 60 m.p.h. and the time interval between the twentieth and fiftieth second of time, and also an enlargement of the corresponding distance-time curves. The heavier lines represent portions of run-curve referred to later.

In using the interpolation method it is necessary to first plot the run-curve upon tracing paper or tracing cloth, after which the curve may be transferred to or reproduced upon another sheet, if desired. A tracing sheet having been placed upon the Chart of Accelerations (Fig. 7) we proceed to plot thereon the portion of run-curve corresponding to the portion $O\ A$ of service run No. 11. The run-curve over this portion will, obviously, begin at zero speed. The form of the curve will depend upon the " net equivalent grade " for this portion, which, according to Table II., is $+\ 0.283\%$, or the same as the actual grade, there being no track curvature. If an acceleration curve for this gradient be plotted in the regular way by the "chart method" beginning the plotting on the tracing sheet at the same point as the acceleration curves on the Chart of Accelerations, this curve will be found to pass between the curve for a level track (solid line) and the curve for a one-half per cent. grade (first dotted line below the solid line), being slightly nearer the dotted line curve than the solid line curve. Let us now proceed to plot the same curve by "interpolation " between the solid line curve and the first dotted line curve. Since 0.283 of *one* per cent. is equal to $0.283 \times 2 = 0.566$ of *one-half* per cent., it follows that the interpolation points will be 0.566 of the space between the two curves aforesaid, reckoning from the solid line curve. In this way any desired number of points may be located between the two curves. In practice the work of doing this may be simplified by using proportional dividers adjusted for the ratio 57:100, or by using proportional scales or other methods of proportional subdivision, well known in the drafting-room. On drawing this curve it will be found to coincide very closely with the curve previously plotted by the chart method. The divergence between the two curves represents the error due to the interpolation method. This error, however, is so slight that, in most cases, it may be considered negligible.

The method of interpolation may also be applied to the distance time curve. The method would, in fact, have relatively little value if this could not be done—its principal advantage being to simplify the operation of " cutting off " each portion of the curve at the proper distance points.

The distance curve corresponding to any interpolated acceleration curve is also prepared by interpolation in exactly the same way as the acceleration curve.

In Fig. 14, in the upper portion of the diagram, the line drawn

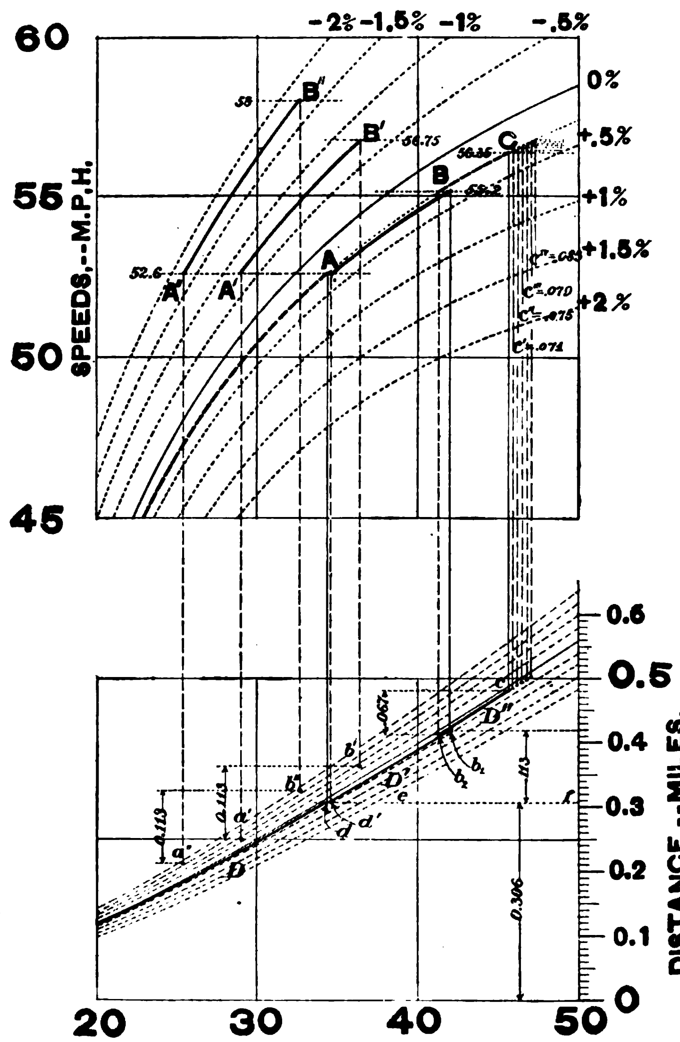

-2% -1.5% -1% -.5%
0%
+.5%
+1%
+1.5%
+2 %
60
55
50
45
SPEEDS,--M.P.H.
58
56.75
56.35
55.2
52.6
B''
B'
B
C
A''
A'
A
0.6
0.5
0.4
0.3
0.2
0.1
0
DISTANCE,--MILES.
0.113
0.306
20
30
40
50

FIG. 14.

with heavy dashes represents the upper end of the run-curve corresponding to the portion of run, $O A$, and in the lower part of the diagram, the heavy line, D, represents the corresponding interpolated distance curve. The process of determining the terminal point A at which this portion of the curve should be cut off, is simple. The length of the portion $O A$ being 0.306 mile, according to Table II., a horizontal line e-f, is to be drawn in pencil on the tracing sheet at a point equal to this distance, when measured by reference to the distance scale at the point f, at the right-hand end of the diagram. This line is prolonged to the left until it intersects the distance curve D, at the point d. A vertical line ($d A$) is then drawn in pencil at this point until it meets the run-curve at the point A, which will be the terminal point, or the point at which the portion of the curve $O A$ is to be cut off. The point A corresponds in this particular case to a speed of 52.6 m.p.h., as indicated on the diagram.

We will now proceed to plot the second portion ($A B$) of the run-curve, which, according to Table II., is 0.113 mile in length, on an up-grade of 0.283 %, and has a track curve of 1° 30′, the net equivalent grade, including correction for track curvature, being + 0.351% (Column VII.). Without disturbing the tracing sheet, a portion of acceleration curve, corresponding to the portion of run $A B$, is to be plotted and drawn on the sheet. This portion of run-curve will obviously begin at some point on the horizontal dotted speed line passing through the terminal point A of the portion $O A$. If the " equivalent " grade (Column VII.) were, for example,—1.75%, the curve would begin at the point A'' and would have the form represented by the heavy full line $A'' B''$. If the equivalent grade were − 0.75%, the curve would begin at the point A' and it would extend to the point B'. For the actual equivalent grade (+ 0.351%), the curve will begin at A and will run to B, being located about 0.7 of the distance between the curves for 0% and + 0.5%, so that it passes slightly to the right of the continuation of the previous curve (shown in dotted line).

To determine the length of the second portion ($A B$), we first drop a vertical line ($A d'$) from the beginning of this portion as far as the corresponding interpolation point (d') in the portion of the chart giving the distance curves. If this portion of run-curve were on a − 0.75% grade, beginning at A', the proper " interpolation " point in the distance curve would be at a', while if the curve were on a − 1.75% grade, beginning at A'', the proper interpolation point would be at a''. Wherever this point may fall, the procedure will be the same; a horizontal line is to be drawn on the tracing sheet, in pencil, at a distance which, measured by the distance scale, at the right-hand end of the diagram, represents the length of the portion of run A B, namely, 0.113 mile, as given in Table II. On this line the terminal interpolation point (b_1) is located. The interpolated distance curve (D') itself may then be drawn, if desired, although that is scarcely necessary, it being sufficient to have the terminal point clearly indicated by a dot, such as shown at b'' and b'. A vertical line drawn from the terminal point to meet the interpolated acceleration curve will cut the curve at the proper time point. If drawn from the point b'' this line would cut the curve A'' B'' at B''; if drawn from b' it would cut the curve A' B' at B'; in the actual case, the proper line is the line b_1B which cuts the curve A B at the point B (55.2 m.p.h.). The acceleration curves B' B'' have been purposely added to the diagram, in this case, to show graphically the important effect produced on the form of the acceleration curve by variations in grade. These curves show graphically the fact that the rate of acceleration increases greatly with the percentage of down-grade, the direct effect of this, of course, being that the speed attained at the end of the corresponding portion of the run is very much higher on down-grades of higher percentage, as clearly shown by the relative positions of the terminal points, B, B', B''.

In the third portion of run, B E, it becomes necessary to anticipate, and to make allowance for, the track curve of short radius, which occurs in the fourth portion (C H). The speed at the end of the portion B E, or the beginning of the portion E H, is, as previously stated, set at 25 m.p.h. This is, therefore, a case in which we must plot in both directions—" forward " from the point B, and " backward " from the point E. The portion B-C-E will have three " component " curves, including an acceleration portion, B C, a drifting portion, C D, and a braking portion, D E. The real problem in this case is the determination of the points C, D, at which the drifting curve C D will begin and end. This has to be done largely by a " cut-and-try " process. We begin by plotting an acceleration curve for a net grade of $+0.283\%$, starting from the speed point B, (55.2 m.p.h.) and making the curve arbitrarily of some convenient length, such as may be thought suitable for the purpose. A vertical line (B-b_2) is dropped from the beginning of the portion B C to the proper interpolation point for the corresponding distance curve D''. Near the end of the portion plotted, a certain number of vertical lines (c', c'', c''', etc.) are dropped from the acceleration curve to the distance curve, and the distance corresponding to each of these vertical lines having been noted by reference to the distance scale, it is recorded in pencil opposite the letter or symbol representing each line, as indicated in the upper right-hand portion in Fig. 14. Thus, in Fig. 14, the distance covered, when the curve $B\ C$ is cut off by the vertical line, c, would be 0.67 mile. The corresponding distances, when the curve is cut off by the vertical lines, c', c'', c''', etc., would be, respectively, 0.071, 0.075, 0.070 mile, etc., each successive line representing a " slice " whose area represents a distance of 0.004 mile. The number of such vertical lines, and their distance apart, may, of course, be varied as desired, and as may seem best in each particular case.

The next step is to lay out a braking curve, working backward from the point E. This case is analogous to the upper portions ($F\ G$ and $G\ H$) of the braking curve in Fig. 12, and, consequently, will correspond with either problem 2 or problem 3 in Appendix D, according to the term which is made the unknown quantity. It will correspond to problem 2 when the distance covered, s, is given, and the entering speed (at the point D), is the unknown quantity to be determined. It will correspond to problem 3 when the entering speed is assumed, and the distance covered, s, is the unknown quantity to be determined. It may be necessary to try both ways, assuming a given value for the distance in the first case, and for the entering speed in the second case. A few preliminary calculations made both ways, based upon different assumptions, will enable a rough approximation to be made, both as to the distance covered and the entering speed, for the braking portion of the curve.

The next step is to plot, on a separate tracing sheet placed upon the chart of retardations (Fig. 8), a portion of drifting curve corresponding to the net equivalent grade (+ 0.283%) indicated in Table II., and of such length as may seem proper to form a connecting link between the points C and D, allowing extra length at both ends. The corresponding distance curve is to be drawn, by interpolation, on the same sheet. This sheet is then superposed upon the tracing sheet containing the acceleration portions. Let us assume that it has been superposed in such manner that the upper end of the drifting curve crosses the continuation of the acceleration curve, $B\ C$ (in Fig. 14), at a point corresponding to the vertical line, c'''. If preliminary calculations have been made for the braking curve in the manner previously indicated, the distance covered while braking, as obtained from these calculations, should be added to the distance covered during the acceleration portion $B\ C\ c'''$, which, as indicated in Fig. 14, is 0.079 mile. The sum of the two distances corresponding to the braking and accelerating portions, subtracted from the total distance of the portion $B\ E$, namely, 0.374 mile, will give the distance remaining for the drifting curve ($C\ D$). If this calculated distance is greater than the distance indicated by the distance curve corresponding to the portion of drifting curves comprised between the vertical line, c''', and the vertical line corresponding to the assumed entering speed, D, it is an indication that this assumed value for the entering speed, D, is too high, or that the acceleration curve has been cut off too soon; and *vice versa*. We may first try the effect of changing the entering speed, D, and of locating it at different points along the drifting curve. In this case, the entering speed, D, being now known, we have a case corresponding with problem 3 (Appendix D), and the distance covered is to be determined by reference to equation (i). The effect of changing the point D, however, is to also change the distance covered by the drifting curve. It may, therefore, be necessary to change the relation of the drifting curve to the acceleration curve, so as to change the point of intersection between these two curves. In many cases, the distance allowed for braking can be fixed, and, consequently, the entering speed, D, can be calculated as a case of problem 2 in Appendix D, by means of Formula (l). This being done, the lower speed point of the drifting curve will also become fixed, and it will now be possible to make sub-divisions at the upper portion of the drifting curve similar to those made on the acceleration curve in Fig. 14, by the vertical lines, c, c', c'', c''', etc., the distance corresponding to each line being recorded in pencil on the tracing sheet. When this can be done, the process of finding the point C becomes greatly simplified. For each position of the drifting curve, with respect to the acceleration curve, the distance values corresponding to the two component curves can be readily calculated. If the sum of the two distances is too small, the two curves must be moved farther apart; if too large, they must be brought closer together. In the actual case, the proper point of intersection between the acceleration curve, $B\ C$, and the drifting curve. $C\ D$, takes place at the point C, corresponding to the vertical line $C\ c$, representing a distance covered, under acceleration (Fig. 14), of .067 mile, the speed at the point C being 56.35 m.p.h. The drifting curve beginning at this point continues until the speed has fallen down to 53.2 m.p.h., the distance covered being 0.129 mile. (Fig. 13.) The braking curve represents a reduction of speed from 53.2 m.p.h. to 25 m.p.h., and a distance covered of 0.178 mile. The three component curves for this portion of the run aggregate exactly 0.374 mile, which is the distance given in Table II.

The fourth portion of the run ($E\ H$) also has three component curves, the first being an acceleration curve, which is to be plotted by interpolation, in the manner already described. It is cut off arbitrarily when it reaches the speed point of 35 m.p.h., that being, as already stated, the limit of speed for the track curvature occurring in this portion of the run. The distance covered is determined by the interpolated distance-curve, in the manner already indicated. A drifting curve for the portion $F\ G$ is then plotted, either on a separate sheet or by placing the same sheet over the Chart of Retardations. The length of this drifting curve may be varied arbitrarily. This being an express run, it is desirable to regain a higher speed with as little delay as possible when leaving the curve. It is usual to turn on the current and to let the train again accelerate in speed before passing entirely out of the curve, it being found practicable and safe to run out of a curve at a considerably higher speed than would be allowable at the beginning, or in the first portion of the curve. In this case the current was turned on after drifting down to a speed of 31.1 m.p.h. and at a point .041 mile from the end of the curve. The acceleration curve, $G\ H$, having been plotted by interpolation in the way already indicated, and having been cut off by means of the distance curve, at the point corresponding to the proper distance (.041 mile), the two succeeding portions, $H\ I$ and $I\ J$, could then be plotted without difficulty, either on the same sheet, or on separate sheets. On reaching the point J it becomes necessary again to anticipate for the final braking at the end of the run, and to plot both ways. The process to be followed in determining the point K is substantially the same as that followed for determining the point C, and need not be further detailed.

After all the " component " portions of the entire run curve have been determined they are to be assembled on one sheet. This can be done easily by tracing these portions on another tracing sheet, or the curves may be redrawn on a separate sheet, after a certain number of coördinate points for each portion have been plotted on the sheet.

The curve *D D D* in Fig. 13 is the distance-curve obtained by integrating the service-run curve, *O A B C*........ .*N*. Its highest point corresponds, by reference to the scale of distance, exactly with the total length of the run (namely, 1.625 mile). The various bends in the curve are an indication of the irregularities in the service-run curve. The height of the curve at any time point, when gauged by the distance scale, measures the distance covered up to that time point.

Subsidiary Curves.—After the service-run curve has been plotted, it becomes possible to plot various other curves, which could not be plotted without it, and which, for this reason, are sometimes designated by the general term, " subsidiary curves." The complete discussion of these curves is beyond the scope of this paper, but some of the curves are so closely related to the service-run curve that a brief reference to them is really necessary, in order to give a general idea, at least,of some of the important uses which may be made of the service-run curve, in determining many of the important factors of a given electric railroad problem. The distance curve, *D D D*, just referred to, in Fig. 13, is an example of a " subsidiary curve." The most important of these curves are the electric power input curves, the current-input curves and also the integral curves derived from them.

The power-input curve is a time-function curve, showing the instantaneous values of the energy applied to a train. This curve begins when the current is applied to the motors, and it ends when the current is cut off. Each acceleration cycle in the service-run curve, therefore, corresponds to and is characterized by a power input curve (and also an energy-input curve). Thus, in service run No. 7 (Fig. 12), in which, as already seen, there is only one acceleration cycle, there is only one power-input curve, which is indicated by a dotted line in the figure. On the other hand, in Fig. 13, where there are three acceleration cycles, there are also three power-input curves, which form the outlines of the three shaded areas in the figure.

The power-input curve and its integral curve, the energy-input curve, serve for the determination of many important factors, including the energy required for a given service, and also the size and character of power station necessary. The coördinate points for the power-input curve are calculated by reference to the " corrected " speed curve (*C*) on the sheet of motor characteristics (Fig. 5). The current value, corresponding to each speed value, multiplied by the mean voltage available at the motor terminals, gives the power value in watts corresponding to that speed. In this way, the power values corresponding to all the speeds may be calculated. These values may also be plotted in the form of a power characteristic curve, in which speed and electric power (preferably expressed in kilowatts) are the coördinates. It should be borne in mind that when the series-parallel system of motor control is used, the energy applied to the motors, while the motors are connected in series, as is the case when running below a certain critical speed, will be, for a given current value per motor, only one-half as much as when the motors are connected in parallel. In the case of the two service runs shown in Figs. 12 and 13, the critical speed at which the change from series to parallel connection occurs, is 19.6 m.p.h. This circumstance accounts for the low portion of the power curve at the beginning, as indicated at P in Fig. 13. The voltage available at the motor terminals is not really applied to the motors themselves, as is well known, until the controller resistance has been entirely cut out. However, since, in reality, we desire to know the energy *applied to the train*, whether this energy be applied wholly to the motors themselves or whether it be partly expended in heating the controller resistance, the portion P is plotted just as if the energy were expended entirely in the motors. In this case each car is assumed to have a four-motor equipment, and the acceleration current, as previously stated, is assumed to have a mean value of 400 amps. per motor. The mean voltage is assumed to be 600 volts. At the time of starting, there being two pairs of motors connected in series per car, the power input will be:

$$600 \times 400 \times 2 = 480 \text{ kw.}$$

This is the ordinate value of the portion P of the power curve, as will be found by reference to the scale of kilowatts per car at the left-hand end of the diagram in Fig. 13.

After the resistance has been entirely cut out, the rate of acceleration would diminish, unless the controller is changed from the series to the parallel connection. This will be made clear by a comparison of the acceleration curves marked A and C in Fig. 11. The lower of the two curves marked A is substantially the same as the acceleration curve for level track (solid line) in Fig. 7. The lower curve marked C is the acceleration curve that would be obtained if the parallel connection were not used—that is to say, if the acceleration were allowed to take place on the last step of the series connection, with the motors still connected in series, but with the controller resistance entirely cut out. (The upper curve in each case is that which corresponds to a higher gearing ratio than the gearing ratio used for the curves shown in Fig. 7.) When the change from series to parallel connection takes place, the total current per car will jump from 800 to 1600 amperes, and the power input curve also instantly jumps up to twice its value; it attains its highest point, *Q*, and there remains constant, as indicated by the straight line, until the controller resistance has again successively and entirely been cut out (when the speed has risen to 39.2 m.p.h.). It is at this moment that the acceleration begins to decrease (in accordance with the curves shown in Fig. 7, or with the curve *A*, shown in Fig. 11), because the counter e.m.f. due to the increase of speed, begins to reduce the current passing through the motors. The power applied to the car, therefore, begins to fall very rapidly, as indicated by the curved portion (*R*) of the power input curve in Fig. 13. The point (*C*) in Fig. 13 being, as we previously found, the point at which the acceleration ceases, it of necessity corresponds to the point at which the power is cut off; and the power curve suddenly drops down to zero at that point. In the second acceleration cycle, in Fig. 13, the speed (25 m.p.h.) at which the current is turned on, is higher than the "critical" speed; consequently, the motor controller must be in the parallel position, with only a part of the resistance cut out. As the whole of this resistance has not yet been cut off by the time the speed point *F* is reached, where the current is again turned off, it follows that the power curve (*S*) will be straight. In the power curve corresponding to the third acceleration cycle, the curve begins with a straight portion, but as the speed soon attains the point (39.2 m.p.h.) at which the controller resistance is all cut out, the power values again rapidly diminish same as in the first cycle, as indicated by the curved portion, *U*.

It should be noted that the portions, *P*, *Q*, *S*, *T*, will not, in actual practice, be absolutely straight lines. They will, in reality, be serrated or saw-shaped, with a number of humps or notches equal to the number of steps in the controller, or equal, rather, to the number of movements of the controller which the motorman makes during acceleration. These humps or notches are due to the fact that when the controller is moved from one step to the next, the current instantly jumps up to a higher value.

and is then gradually reduced by the increase in e.m.f. due to the rising speed of the motor, the same process being repeated for each step or notch of the controller. With the Sprague multiple-unit system of control, it is possible to restrict, to some extent, the amount of fluctuation in current while the controller resistance is being cut out, so that the notches or teeth in the actual energy curve at the points P, Q, etc., will not be so large. This is due to the fact that the process of cutting out the controller resistance can, in this system, be made automatic, being controlled by the current passing through each motor. These current fluctuations theoretically react upon the acceleration, and tend to produce slight waves in the acceleration curves. Practically, however, their influence is negligible, being virtually obliterated by the inertia of the car.

Energy Curve.—If we integrate the area of each power or kilowatt curve, we obtain the value of the energy in kilowatt seconds (which, divided by 3600, gives the kilowatt hours), expended during the corresponding acceleration cycle. This is a valuable and useful quantity. If we integrate the power curve " by parts," we obtain the energy curve for each acceleration cycle. This has been done in Fig. 13, where the portions of curve, Ea, $E\,b$, $E\,c$, represent, respectively, the portions of energy input curve corresponding to the three acceleration cycles. The horizontal portions between the inclined portions merely indicate the fact that the total energy remains stationary between the different cycles. The aggregate energy for the three cycles, when read by reference to the scale of kilowatt-hours per car at the right-hand end of the diagram, will be found to be 14.22 kilowatt-hours. The portion of the total energy corresponding to each cycle may, likewise, be read separately by reference to the same scale.

Energy Consumption.—Having obtained from the energy curve the energy consumption during the run, and the weight of train and length of run being both known, the energy required in watt-hours per car-mile, or per ton-mile, may be easily calculated. The resulting data are given in Fig. 12 and Fig. 13. It will be seen that while, in Fig. 13, the energy consumption is only 114 watt-hours per ton mile, it rises, in Fig. 14, to 168 watt-hours per ton-mile, notwithstanding the fact that run No. 11 is shorter than run No. 7. This is, of course, due entirely to the presence of the sharp curve in run No. 11, which necessitates reduction of speed and subsequent accelerations, as already indicated.

Current-Input Curve.—The current-input curve is obviously of exactly the same form as the power-input curve, its ordinate values being different from those of the power curve by a constant equal to the mean voltage assumed in computing the ordinates of the power curve. The current curve may, therefore, be derived from the power curve, or the power curve itself may be used, as if it were the current curve, with a different scale of ordinates. The current curve is useful in calculations regarding the feeder and distributing systems necessary for transmitting electrical energy to the car motors. It is also useful in determining the losses to be expected in the conductors as well as in determining the heating of the motors. For the latter purpose the current input curve should be integrated twice successively. The first integration gives ampere seconds (coulombs) from which (dividing by 3600) we get "ampere hours." From the second integration the value of the *mean square* can be obtained; the square root of this value will be the equivalent heating current for the run. The work of integration will be greatly simplified by the use of an integraph or of a so-called mechanical integrator. The well-known, highly ingenious "Amsler mechanical integrator" has been found by the writer to be very convenient and satisfactory for this purpose. While it does not draw the integral curves, like the integraph, it has the advantage over the integraph, in this case, of giving at one single operation the results of both integrations, namely, the current-time integral or the coulombs $(a\int y\,dx)$ and the current-square time integral $(b\int y^2\,dx)$, and even a third integration $(c\int y^3\,dx)$ if desired. A detailed description of the modus operandi is beyond the limits of this paper.

Intrinsic Power Curves.—These curves show the instantaneous values of the power actually utilized in maintaining the speed during the entire run. The formulæ usually employed for calculating these power values give the result in mechanical horsepower. It is preferable, however, to convert the horse-power values into equivalent kilowatt values. The curve showing the instantaneous power values has been called the "intrinsic power curve." The integral of this curve would be another curve called the intrinsic energy curve. When the intrinsic energy curve and the energy-input curve are both drawn to the same scale the ratio of final ordinates of the intrinsic energy curve to the energy-input curve, will represent the mechanical efficiency attained during the run.

The intrinsic power and energy curves are of interest and of utility in the minute analysis of railway problems.

APPENDIX A.

(Analytical Definitions.)

Time-Function Curves of Rectilinear Motion.

Motion and Velocity.—The phenomenon of motion being the natural starting-point in the analytical study of the speed-time curve, we may begin by noting some of its characteristics.

According to the definition given by the late Prof. S. W. Holman, in his able work on "Matter, Energy, Force and Work" (page 12), "*Motion is change of relative position.*" It is symbolized by *distance* and may be estimated and measured by reference either to its *amount* or to its *rate.*

The *amount of motion* of a body is equal to the length of the line (called "path") along which the motion takes place.

The *rate of motion* of a body is the proportional amount of its motion estimated by reference to some basis or unit of comparison. Time being the most convenient and practicable basis of comparison or proportion, the rate of motion, when estimated with reference to time, is equal to the change in amount of motion (or the variation of distance, or space) occurring in a definite interval of time, and it is then called the *time* rate of motion or the *time* rate of space variation. Thus, when distance is expressed in miles, and time values in hours, the rate of motion will be equal to the quotient of the distance divided by the time consumed in moving over the given distance. In this case the quotient would be "miles per hour," which is the numerical measure of speed or velocity. Hence, *velocity is equal to the time-rate of motion*, or

$$v = \frac{ds}{dt} \qquad (a)$$

whose value would be:

$$v = \text{miles} \div \text{hours} = \text{miles per hour}$$

where

v = instantaneous velocity or speed (m.p.h.)
s = distance (space)
t = time (seconds)

If in Fig. 15 the ordinates be used to represent amounts of motion or distances, expressed, say, in feet, and if the abscissæ be used to represent time values, say, in seconds, then the curve O A B C D will represent the relation between any distance and the time required to pass over it by a moving body.

The amount of motion which has taken place between any two points, as A and B, on the curve, will be measured by the vertical distance dy ($= y' - y$) between these two points. This amount of motion has taken place in the space of time dx ($= x' - x$),

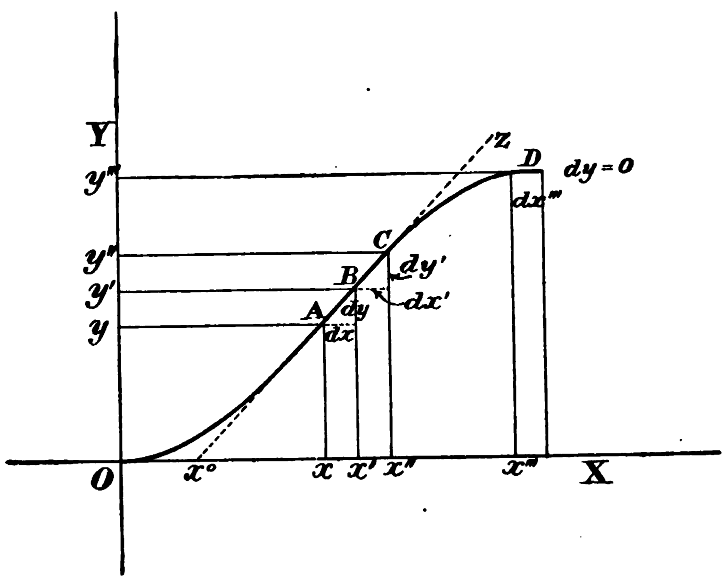


FIG. 15.

comprised between the two time intervals x and x'. Hence the amount of motion in unit time (*i. e.*, the time-rate of motion), or the velocity, will be

$$\frac{y' - y}{x' - x} = \frac{dy}{dx} \quad = \text{feet per second.}$$

Let the (dotted) line, x^o - - - z, be drawn tangent to the middle point of the portion of the curve comprised between the points A and B. Then, by similar triangles, we have

$$\frac{dy}{dx} = \frac{Bx'}{x^o x'} = \frac{y'}{(x' - x^o)} = \tan B\, x^o\, x'$$

A similar relation would obtain in the case of a line drawn tangent to any other point whatever of the curve. Hence, the differential coefficient $dy \div dx$, or the tangent, at any point of the curve, is numerically equal to the time-rate of motion, or the *velocity*, at that point.

The precise numerical value of the differential coefficient, for any point of the curve, will depend upon the angularity of the tangent line (analogous to the line x° - - - z) at that point. For an angle of 90°, corresponding to any portion of the curve having an exactly vertical direction, we have $dx = 0$, while dy = a finite quantity, and consequently, the value of the tangent being infinity, (as is well known from trigonometry), we will have

$$\frac{dy}{dx} = \frac{dy}{0} = \tan 90^\circ = v = \text{infinity},$$

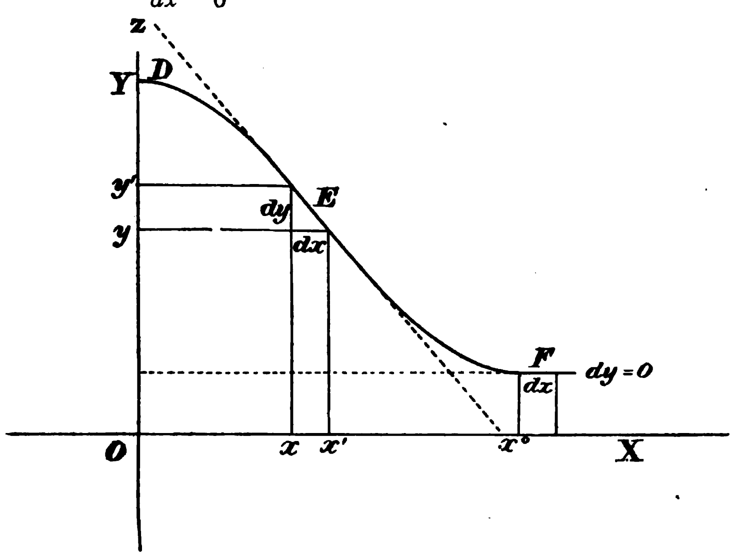


FIG. 16.

that is to say, the velocity will be infinite. For an angle of 0° corresponding to any portion (D) of the curve which is exactly horizontal, we have $dy = 0$, while dx = a finite quantity, and consequently, we will have

$$\frac{dy}{dx} = \frac{0}{dx} = \tan 0^\circ = v = \text{zero}$$

that is to say, zero velocity, *i. e.*, absolute rest.

A curve such as shown in Fig. 15 is, in reality, a " distance-time " curve, but is usually called, simply, a *distance curve.* From the preceding anaylsis, it will be readily seen that the slope of the curve or the angle which it makes with the axis of x, is an indication and a measure of the velocity of the moving body. It is also an indication of the *direction* of motion, for, as will be seen, the elemental motion (dy) taking place in the time (dx) is *upward*, since the space increment (dy) when measured on the scale of ordinates, represents the progression from the point y to the point y'.

In Fig. 16 we have a distance time curve having a general downward slope. In this case, the elemental motion (dy), taking place in the elemental time (dx), is downward, since it represents the progression from the upper ordinate y' to the lower ordinate y. In such a case, the space increment (dy) would have a negative sign, and, consequently, the differential coefficient $\frac{dy}{dx}$ would have the negative sign.

It follows, therefore, that in any distance-time curve, when the differential coefficient has a positive sign, it indicates motion in one direction (*i. e.* upward), and when it has a negative sign, it indicates motion in the contrary direction (*i. e.* downward.)

The distance-time curve is related in an interesting manner to the speed-time curve, which we now proceed to consider analytically.

In a speed-time curve (Figs. 1, 2, 3), the ordinate values (y) represent instantaneous values of speed, or velocity, as previously stated. We, therefore, have (from equation a),

$$y = \frac{ds}{dt} = v \qquad (b)$$

It follows that *the ordinates of a speed-time curve are proportional to the differential coefficients*, or the tangents, of a corresponding distance-time curve. Reciprocally, since integration is the reverse of differentiation: *Any distance-time curve may be regarded as the integral curve of a corresponding speed-time curve.* This is a very important and useful relation which may also be established in another manner.

The area (da) enclosed by any small portion of a speed-time curve corresponding to the time-element dt is

$$da = y\,dt$$

Substituting for y, according to equation (b), we have

$$da = \frac{ds\,dt}{dt} = ds \qquad (c)$$

or the elemental area of a speed-time curve is the equivalent of an elemental distance (ds). This elemental distance is equal to the difference in the ordinate values of a corresponding distance-time curve taken between the same time points.

The equivalent of ds, by equation (b), is

$$ds = v\,dt \qquad (d)$$

The integration of the speed-time curve between any two time points such as t^0 and t' will give

$$A = \int_{t^0}^{t'} v\,dt = s \qquad (e)$$

in which

A = the area of the portion of the speed-time curve comprised between the time values t^0 and t'.

and

s = the distance traversed in the interval of time t^0, t'.

By reversing the process, or differentiating, we return readily from equation (e) to equation (d), and thence to equation (b), which was our starting point.

The above relationship between the distance-time and the speed-time curves is utilized to advantage in plotting the "run" curves.

[This relationship was mentioned as early as 1885, by M. Bruno Abdank-Abakanowicz, in one of his serial articles on the "Integraph," published in *La Lumiére Electrique* (Vol. XVIII, pp. 538-539), and reprinted in his work "Les Intégraphes," 1886, pp. 117-119.]

Variable Velocity and Acceleration.—Velocity, like motion itself, may be estimated by reference either to its *amount* or to its *rate*.

I. *Amount of Velocity.*—The *amount* of *velocity* (or the amount of speed) of a moving body, is the difference between two definite given velocities of said body. The two velocities by reference to which amount of velocity is determined, are sometimes called the "initial" and "final" states "of motion," or "velocities" of the body.

Equation (a) suggests at once the following analytic definition.

Amount of velocity is the difference between two given time-rates of motion of a body. In symbols we have, for the amount of velocity,

$$v'' = v' - v^{\circ} = \frac{d\,s'}{dt} - \frac{ds^{\circ}}{dt} \qquad (f)$$

where

v'' = amount of velocity
v° = initial velocity
v' = final velocity

When the initial velocity v° = zero, we have

$$v'' = v' \qquad (g)$$

In this case the amount of velocity is the *total* velocity. This is the quantity generally meant when we speak of a speed of so many miles or kilometres per hour, or so many feet or metres per second.

When the initial velocity is lower than the final velocity, equation (*f*) gives a positive value for v'', and we have a *gain* or *increase* in velocity, *which is acceleration*. The motion taking place under these conditions is called *accelerated motion*.

The following statements should be carefully noted:

Acceleration is increase in velocity.

It is measured in *miles per hour*, like velocity.

This is not the usual acceptation of the term acceleration, which, as we shall see later, is used, ordinarily, in a figurative sense, instead of " *time-rate of acceleration*."

When the initial velocity is higher than the final velocity, then equation (*f*) gives a negative value for v'', and we then have a *loss* or *decrease* in velocity, which is *retardation*. The motion so conditioned is called *retarded motion*.

Retardation is decrease of velocity, and is measured in miles per hour, like velocity.

Since a loss or decrease is a negative gain or increase, it follows that retardation is, analytically, the same as *negative acceleration;* and it is in practice often designated by that term.

If the initial and final states of motion are exactly the same, equation (*f*) gives v'' = 0, and we have " *constant* " speed or velocity.

In the speed-time curve in Fig. 1, the points A, B, C, correspond respectively to speeds of 55, 60 and 65 m.p.h. These figures represent the *total* velocity at the corresponding points. Reckoning from rest or zero velocity, there has been an increase in velocity, or an acceleration of 55 m.p.h. at the point A, of 60 m.p.h. at the point B and of 65 m.p.h. at the point C. The *gain in velocity*, or the *acceleration* between one point and the next, is equal to 5 m.p.h.

In Fig. 2, the points A. B, C, D correspond to speeds which are respectively 60, 50, 40 and 30 m.p.h. These figures represent the total velocity as before, but in this case the total velocity decreases from one point to the next, there being a *loss* of velocity or *retardation* of 10 m.p.h. between any one point and the next.

It will be noted that the time required to bring about the same acceleration or retardation is not the same between A and B, as between B and C. This shows that *acceleration* (using the term in the sense hereinabove defined), and *retardation*, are independent of time.

Between the points D and E, in Fig. 1, there is no gain or loss in velocity, or, in other words, there is no acceleration or retardation, the speed line being perfectly horizontal, thereby indicating *constant* or *uniform velocity.*

II. *Rate of Velocity.*—The rate of velocity which is most suitable for practical use is the *time-rate* of velocity, which is

$$\frac{dv}{dt}$$

where

$$v = \text{velocity}$$

and

$$t = \text{time}$$

We at once recognize this as being also the expression for the differential coefficient of a speed-time curve at any point.

Since, according to equation (*b*), the ordinate of a speed-time curve is already equal to a time-rate of motion, its differential coefficient, or the time rate of variation, at any point of the curve, will be equivalent to the second differential coefficient of a corresponding distance-time curve, or

$$\frac{dv}{dt} = \frac{d\left(\frac{ds}{dt}\right)}{dt} = \frac{d^2s}{dt^2} \qquad (g)$$

We see at once that while the differential coefficient of the distance-time curve $\left(\frac{ds}{dt}\right)$ indicated *amount* of velocity, the differential coefficient of the speed-time curve indicates *time-rate* of velocity. Since time-rate of velocity is equal to change in amount of speed (*or acceleration*) per unit time, it follows that it is equal to *time-rate of acceleration.* We therefore have

$$\frac{dv}{dt} = \frac{d^2s}{dt^2} = \text{time rate of acceleration.} \qquad (k)$$

for which the term " acceleration " is usually employed. The term " *rate of acceleration* " or " *acceleration rate* " would be more proper. The writer has sometimes used the term " *acceleration coefficient.*"

When acceleration is measured in miles per hour, as is usual in this country, we have

$$\frac{dv}{dt} = \frac{\text{Acceleration}}{\text{time}}$$

$$= \frac{\text{miles per hour}}{\text{seconds}}$$

$$= \text{miles per hour per second}$$

When $\frac{dv}{dt} = 0$, we have a horizontal speed line indicating zero acceleration.

When $\frac{dv}{dt}$ = a positive quantity, we have an upward slope in the curve, indicating increase in acceleration.

When $\frac{dv}{dt}$ = a negative quantity, we have a downward slope in the curve, indicating negative acceleration or retardation.

APPENDIX B.

Train Acceleration.

Derivation of Fundamental Formulæ.

The fundamental formulæ relating to Train Acceleration are derived directly from the formulæ for mechanical energy and mechanical work.

The mechanical work done by a source of energy in moving a body over a given distance is a measure of the mechanical energy usefully expended in doing this work, and it is equal to the product of the propelling force acting against the body by the distance over which the body has travelled, or

$$E = Fs \qquad (1)$$

from which we have

$$F = \frac{E}{s} \qquad (1a)$$

where

E = Energy (or work)

F = Force exerted (in causing pressure, push or pull)
s = Distance travelled.

The above (1) is the equation of *potential energy.* When considering the changes of energy in a *moving* body, especially where the force exerted does not remain constant, the equation may be modified so as to estimate separately the energy for each small element (ds) of the distance travelled, thus:

$$d\,E = F\,ds \tag{2}$$

the total energy corresponding to the whole distance being, in that case,

$$E = \int_0^s F\,ds$$

The distance factor of the energy developed may be expressed in terms of the velocity of the body at each instant of time. Velocity being, itself, a time-rate of space variation, we have

$$v = \frac{ds}{dt} \tag{3}$$

whence

$$v\,dt = ds \tag{3a}$$

where

v = velocity
t = time

Substituting this value of ds in equation (2) we have

$$d\,E = F\,v\,dt$$

which expresses the change in the mechanical energy imparted to a moving body at each instant of time. We also have

$$\frac{d\,E}{dt} = F\,v \tag{4}$$

or, " the time-rate of variation of energy is equal to the product of force by velocity."

The kinetic energy of a moving body, according to the well-known formula, is

$$E = \frac{M\,v^2}{2} \tag{5}$$

in which M = the mass of the moving body.

Differentiating with respect to v, we have

$$d\,E = M\,v\,dv$$

which expresses the change in the mechanical energy imparted to a moving body at each change of speed. Dividing by dt (*i.e.*, differentiating with respect to time, and taking the derivative), we have

$$\frac{dE}{dt} = M\,v\,\frac{dv}{dt} \tag{6}$$

which is another expression for the time-rate of variation of energy.

Equating (4) and (6), we have

$$F\,v = M\,v\,\frac{dv}{dt}$$

whence

$$F = M\,\frac{dv}{dt} \tag{7}$$

but $dv \div dt$ is the time-rate of change of velocity, ***which is rate of acceleration***. [This can be readily seen from equation (3); by differentiating with respect to time (t) we have the second derivative

$$\frac{dv}{dt} = \frac{d^2s}{dt^2}$$

which is the same as equations (g) and (h), in Appendix A.]

Hence, if we designate this time-rate by the symbol A, we obtain the well-known fundamental equation

$$F = M\,A \tag{8}$$

which states that "*force is equal to the product of mass by rate of acceleration*"; from which we derive

$$A = \frac{F}{M} \tag{9}$$

his equation, which expresses the relation between the acceleration produced in a given mass and the force acting upon it, is the fundamental equation for acceleration. The formula requires modification in order to make it convenient for practical use. The mass (M) should be expressed in terms of weight. The rate of acceleration (A) should be based on increments of velocity, stated in miles per hour, and the force (F) should be expressed as a pull in pounds per ton.

The force of acceleration is usually estimated in "gravity-measure," that is to say, by reference to the acceleration produced in a falling body by the action of gravity.

The distance travelled by a falling body is

$$s = \frac{gt^2}{2} \tag{10}$$

where

g = the acceleration constant due to gravity
t = time (in seconds)
s = distance travelled (in feet)

The velocity of the falling body is

$$\frac{ds}{dt} = gt = v \tag{11}$$

and its rate of acceleration is

$$\frac{d^2s}{dt^2} = g = \frac{dv}{dt} \tag{12}$$

The force exerted by gravity is, by equation (8),

$$F = M A \tag{12a}$$

When a body falls and reaches the end of its fall, its potential energy is all converted into kinetic energy. The equation (1) for potential energy may be written

$$E = s w = \text{ft. lbs.}$$

when the force w is expressed in pounds, and the distance s is expressed in feet.

Using equation (5) for the kinetic energy, and equating the two, we have

$$E = \frac{M v^2}{2} = w s \tag{13}$$

Substituting for s its value as given in equation (10), the preceding equation becomes

$$\frac{M v^2}{2} = \frac{w g t^2}{2} \tag{14}$$

whence

$$M v^2 = w g t^2$$

Taking the value of v ($= g\,t$), and substituting for v its value as given in equation (11), the above equation becomes

$$M\,g^2\,t^2 = w\,g\,t^2$$

which reduces to

$$M\,g = w \tag{15}$$

whence we have

$$M = \frac{w}{g} \tag{16}$$

The value of g may be taken as

$$g = 32.2$$

so that mass expressed in gravity measure is equivalent to weight in pounds, divided by 32.2; or, we have

$$M = \frac{w}{g} = \frac{w}{32.2} \tag{17}$$

when w is expressed in pounds.

If we substitute this value for M in the fundamental equation (9) for acceleration, we have

$$A = \frac{F}{\frac{w}{32.2}} \tag{18}$$

or

$$A = \frac{32.2\,F}{w} \tag{18a}$$

F being, according to equation ($1a$), the ratio of the energy to the distance travelled, that is, the pulling force exerted over said distance. This pulling force is expressed in pounds, and when speeds are expressed in feet per second, energy (E) is expressed in foot-pounds and distance (s) is expressed in feet.. The above formula ($18a$), therefore, expresses acceleration as a gain or loss in speed measured in feet per second, obtained during one second, that is to say, the increase or decrease in velocity in feet per second PER SECOND. In dealing practically with train acceleration, the speeds are usually estimated in miles per hour, and the gain in speed per second is, as a rule, expressed as the increase or decrease in miles per hour, PER SECOND. The formula ($18a$), therefore, requires to be modified by a conversion factor expressing the relation between an acceleration of a foot per second per second and a mile per hour per second. Since a mile is equal to 5,280 feet, and an hour is equal to $60 \times 60 = 3{,}600$ seconds, it follows that a velocity of one mile per hour $= \frac{5{,}280}{3{,}600}$ $= 1.467$ feet per second. Using the letter "A" to indicate acceleration in feet per second per second (as in formula (18), and the letter a to indicate acceleration in miles per hour per second, we have the following equation:

$$A = 1{,}467a$$

whence

$$a = \frac{A}{1{,}467}$$

or

$$a = .682A \tag{19}$$

which means that an acceleration of one foot per second PER SECOND is equal to an acceleration of .682 mile per hour PER SECOND.

Therefore, substituting the value of A, as given in equation (18), we have

$$a = .682 \times 32.2 \times \frac{F}{w} \tag{20}$$

in which the numerical value of a is equal to the gain or loss of speed (in miles per hour) per second. If the weight (w) is to be expressed in tons of 2,000 pounds, as is the general practice in this country, we must substitute its value such that

$$w = 2{,}000\ W$$

where

$$W = \text{tons (of 2,000 pounds)}$$

and where

$$w = \text{pounds (lbs.)}$$

This means, simply, that the symbol (W) representing weights IN TONS must be multiplied by 2,000 to give the equivalent weight IN POUNDS. Substituting for w its value, in terms of W, the equation for acceleration (20) becomes

$$a = \frac{d^2s}{dt^2} = \frac{(0.682 \times 32.2)\ F}{2{,}000\ W}$$

$$= \frac{21.96\ F}{2{,}000\ W} \tag{21}$$

$$= \frac{.01098\ F}{W} \tag{21a}$$

Solving for F, we have

$$F = \frac{W\,a}{.01098}$$

$$= 91.1\,W\,a \qquad (22)$$

If we are considering the force (F) corresponding to unit weight ($W = 1$ ton), and unit acceleration ($a = 1$ mile per hour per second), the preceding equation reduces to

$$F = 91.1$$

This means that an effort or pull of 91.1 lbs. is required for each ton of train weight for maintaining acceleration at the rate of one mile per hour per second.

Solving for W, we have

$$W = \frac{.01098\,F}{a} \qquad (23)$$

These three equations (21), (22), (23), give the value of each of the three quantities a, F and W, when the other two are known or assumed. They are the formulæ usually employed in discussing problems in train acceleration. The term F, it should be carefully noted, does not symbolize the TOTAL force applied to, or absorbed by, the train, but only that part of it which is expended in producing acceleration. It is one of the two factors of that portion of the total energy applied to the train which is really *stored* in the train in the form of kinetic energy of momentum; the other factor being (according to the fundamental formula of work, hereinabove), the distance traversed while the force is operating. If the force remain constant in value throughout the entire distance, we have

$E = F\,s$, which is the same as equation (1).

If the force varies at different points, we have

$E = \int F\,ds$, which is the same as equation (2)

In any case where there are other forces besides that which is expended in, and represented by, the production of acceleration, these other forces may also be expressed in *terms of acceleration*, and using the letters F' F'' F''' to represent these forces, the *total* force P, would be:

$$P = F \pm F' \pm F'' \pm F''' \pm \text{etc.} \qquad (24)$$

the sign ($\pm$) being taken to mean that the forces in question may be either such as to produce acceleration, or such as to prevent it. The acceleration (a) which each of these forces would produce by itself, is to be determined by reference to equation (21a) same as the acceleration corresponding to stored energy.

Using the symbols a', a'', a''' to indicate these accelerations, and substituting their value, as given by equation (21a) in equation (24), we have

$$P = 91.1\, W\, a \pm 91.1\, W\, a' \pm 91.1\, W\, a'' \pm 91.1\, W\, a''' \pm \text{etc} \qquad (25)$$

Since 91.1 W is common to all these terms, we may write this equation as follows:

$$P = 91.1\, W\, (a \pm a' \pm a'' \pm a''' \pm \text{etc.}) \qquad (25a)$$

From this equation we have

$$\frac{P}{91.1\, W} = a \pm a' \pm a'' \pm a''' \pm \text{etc.} \qquad (26)$$

But P being the total force, according to equation (25), and the quantity, 91.1 W, being the " converted " measure of mass the quotient of these two quantities represents, according to equation (9) an acceleration which might be called the *total acceleration*. Using the symbol A' to designate this total acceleration, we have

$$A' = 91.1 \frac{P}{W} = a \pm a' \pm a'' \pm a''' \pm \text{etc.} \qquad (27)$$

or the effective acceleration, in any concrete case, is equal to the algebraical sum of the accelerations which would be produced by each of the forces acting independently and alone.

This is a most important deduction which is of great utility and convenience in simplifying the analysis and the plotting of speed-time curves.

Equation (27) may be put in more practical form. The symbols " a " used in this equation in reality represent time-rates of acceleration, as is fully explained in Appendix A; consequently, each one is equal to a time-rate of velocity, ($dv \div dt$). The equation may, therefore, be written

$$A' = \frac{d\,v}{dt} = \frac{d\,v'}{dt} \pm \frac{d\,v''}{dt} \pm \frac{d\,v'''}{dt} \pm \text{etc.} \qquad (28)$$

The analytical statement of the deduction previously noted is, therefore, as follows:

The differential coefficient of an acceleration curve is equal to the algebraical sum of the individual differential coefficients corresponding to the various forces concerned and operating in producing the acceleration, each of these differential coefficients being determined separately just as if it were alone concerned in the result.

Using the letter " k " (as is done in Appendix C), as a symbol to designate a time-rate of velocity, the above equation becomes:

$$A' = k \pm k' \pm k'' \pm \text{etc.} \tag{29}$$

where k, k', k'', etc., represent the values of the differential coefficient, corresponding to the accelerations a, a', a'', etc., in equation (27).

APPENDIX C.

Formula for Time-Values of Speed-Time Curves

The most convenient and practical way of drawing a speed-time curve is to locate or " plot " on a sheet of paper, the coördinates for a certain number of points of the curve, sufficiently close together for the purpose, and to then draw a line passing through or near these points. The more precisely these points have been determined and plotted, and the more numerous they are, the more perfect will be the curve, and the fewer the points which are, so to speak, out of line of the " mean path " through the aggregation of the coördinate points.

The data of each case furnish the necessary information regarding the *speed*, which is the ordinate value for each coördinate point of the curve; but they give no direct information about the *time value* corresponding to each speed value, that is to say, about the horizontal distance of the next ordinate, either from the starting point, or from the last point plotted. Fortunately, the data either give or furnish the information necessary to obtain the value of the differential coefficient, or the time-rate of speed variation, which corresponds to each speed value, and which determines the inclination or slope of the curve at that particular speed point. Taking advantage of this circumstance, a formula for pre-determining the time values corresponding to the speed-values, may be obtained by the solution of a simple geometrical problem. This problem may be stated as follows:

"Given the ordinate (y) and the differential coefficient ($dy \div dx$) at any point of a curve to find the abscissa (x) corresponding to said ordinate, or the distance of said ordinate from the axis of ordinates (OY).

There are two cases:

First.—Curves having a positive differential coefficient, or an *upward* slope.

These curves are generally concave to the axis of x.

This case includes all *acceleration curves.*

Second.—Curves having a negative differential coefficient, or a *downward* slope.

These curves are generally convex to the axis of x.

This case includes all *retardation curves.*

First Case.—(Fig. 17). Let dotted lines a - b, c - d, e - f, be drawn tangent to the curve $O\ E\ F$ at various points. Let the

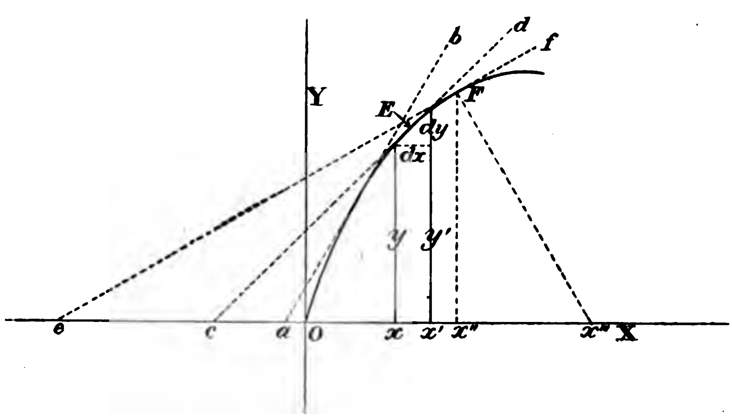


FIG. 17.

vertical lines, y and y', be ordinates which are very close together and correspond to the point of tangency (E). The time space or difference (dx) between these ordinates, or

$$dx = x' - x \qquad (a)$$

and the difference between the ordinates, or the speed increment

$$dy = y' - y \qquad (b)$$

are both assumed to be infinitely small.

By similar triangles, we have

$$\frac{y}{cx} = \frac{dy}{dx} \qquad (c)$$

Or the ordinate (y) at the point of tangency, divided by the "sub-tangent" (cx) is equal to the differential coefficient for the said point. The numerical value (k) of this differential coefficient is known, or can be calculated from the data of the case, so that we have

$$\frac{dy}{dx} = k$$

whence

$$dx = \frac{dy}{k} \qquad (d)$$

It should be noted that dx is really the subtangent of the small or differential triangle $E\,dy\,dx$.

Equation (d) may also be written

$$dx = dy \times \frac{1}{k} \qquad (e)$$

This means that the time element dx, corresponding to the infinitely small change in speed dy, is equal to this change in speed multiplied by the *reciprocal* of the differential coefficient. The total time x' would be, from (a)

$$x' = x + dx \qquad (f)$$

Such time increment values (dx) would be too small for practical use in plotting curves, however.

If we increase the difference between x and x', we will have, instead of equation (a) and (b), the following:

$$x' - x = \Delta x \qquad (g)$$

$$y' - y = \Delta y \qquad (h)$$

and equation (c) will become

$$\Delta x = \Delta y \times \frac{1}{k} \qquad (i)$$

while equation (f) will become

$$x' = x + \Delta x \qquad (ii)$$

when Δy = the speed increment corresponding to the time increment Δx.

An important question arises in this case, however. So long as the time difference was very small (= dx), and the ordinates y and y' remained very close to each other, the differential coefficient had substantially the same numerical value (k) at the ordinate y as at the ordinate y', and no substantial error would result from taking either of the two values of this coefficient.

When the time distance is increased (to Δx), however, the differential coefficients at the two ordinates y and y' may be materially different. This is illustrated in Fig. 18, where the conditions are purposely exaggerated. In this case we have

$$\frac{dy}{dx} = \frac{y}{cx} = k \qquad (j)$$

at the point E, and

$$\frac{dy'}{dx'} = \frac{y'}{ex'} = k' \qquad (k)$$

at the point F,
the two being evidently different in value, and one being evidently larger, the other smaller, than the differential coefficient corresponding to some intermediate point of the curve such as D, between E and F. If we draw the line g, h, parallel to the tangent line g', h', we have the differential triangle E F H, exactly similar to the differential triangle corresponding to the point D, and we

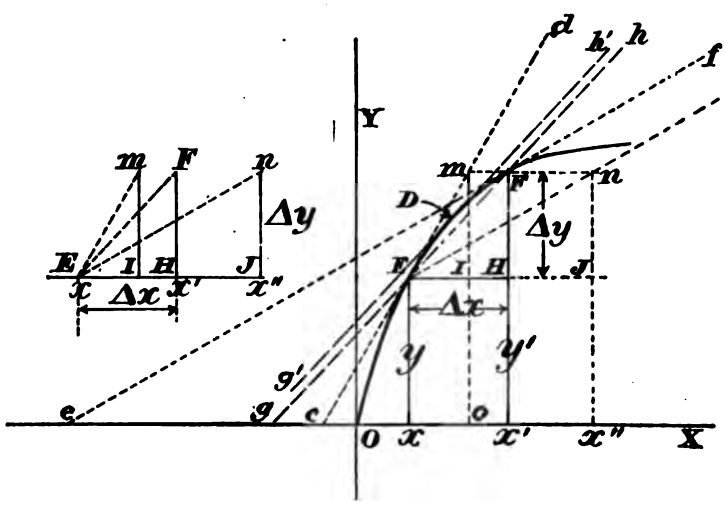


FIG. 18.

can write

$$\frac{dy^\circ}{dx^\circ} = \frac{\Delta y}{\Delta x} = k^\circ \qquad (l)$$

where y°, x° (not shown in the diagram), are the coördinates of the point D, and k° = the differential coefficient thereof.

The differential triangles E m I and E n J correspond, respectively, to the coördinates of the points E and F and to their differential coefficients, k and k', as defined in equations (j) and (k). These two differential triangles and the differential triangle $E\ F\ H$ are reproduced by themselves in the left-hand portion of Fig. 18.

As pointed out in connection with equation (d) the subtangent of the differential triangle is the time increment (Δx) in each case. Hence, the three triangles show graphically the different values of Δx obtained by equation (i) when, with the same value of Δy, the different values of the differential coefficients (k, k°, k') corresponding to the points E, D and F, are used.

It is seen that the intermediate coefficient value k° is the one giving the correct time increment value (Δx). The lower value, k, makes the time increment too small by the distance I H; while the higher value, k', makes it too large by the distance H J. The point D is approximately midway between the points E and F. If the curve had a constant rate of curvature, like the arc of a circle, the point D would be exactly midway; it would be shifted to the left if the rate of curvature is decreasing, and to the right if the rate of curvature is increasing. In practice the error in the value of time increment (Δx) will be negligible if the value of the differential coefficient is that corresponding to the midway point or the mean (y'') of the two speed values y, y', such that

$$y'' = \frac{y + y'}{2}$$

and, of course, the nearer the two values y and y' are to each other (or the smaller Δy is taken), the smaller the error.

The error made may easily be calculated. If we designate it by $\Delta x^{\pm}$ we may write, from equation (i)

$$\begin{aligned} \Delta x^{\pm} &= \Delta x' - \Delta x'' \\ &= \frac{\Delta y}{k'} - \frac{\Delta y}{k''} \\ &= \Delta y \left(\frac{1}{k'} - \frac{1}{k''} \right) \\ &= \Delta y \left(\frac{k'' - k'}{k' \, k''} \right) \end{aligned} \qquad (m)$$

where

$\Delta x^{\pm}$ = amount or error,
$\Delta x''$ = the wrong value,
$\Delta x'$ = the correct value,

and the proportion of error would be,

$$\frac{\Delta x^{\pm}}{\Delta x'}$$

The above equation (m) in reality gives the difference in time value resulting from having assumed some greater or less value than the proper value (k') of the differential coefficient. If the value of k'' was taken too great (which is the case symbolized by the differential triangle E m I), the factor $k'' - k'$, and consequently the value of $\Delta x^{\pm}$, representing the correction for error, will have the positive sign. On referring to the first line of equation (m) we see that $\Delta x^{\pm}$ can only have the *plus* sign when $\Delta x''$ or the "wrong" time value is *less* than $\Delta x'$, the correct time value. Hence, the plus sign will mean that the correction is to be made by adding the amount $\Delta x^{\pm}$, obtained by equation (m), to the "incorrect" time value ($\Delta x''$), previously obtained. If the value of k'' was taken too small (as in the case symbolized by the differential triangle E n J), the sign of $\Delta x^{\pm}$ will be *negative* showing that this amount, Δx, is to be subtracted from the incorrect amount, $\Delta x''$.

In practice, the speed differences (Δy) between any two successive points of the curve are expressed in miles per hour, or fractions thereof, and the time values Δx are taken in seconds.

Equation (m) shows that the error would increase in direct proportion with the speed increment (Δy), and in inverse proportion with the product of the reciprocals of the two differential coefficients considered.

(NOTE.—Usually k' and k'' have very nearly the same values, hence the product k', k'' is very nearly equal to the *square* of either k' or k'').

The *total* time value or the abscissa (x') corresponding to any speed point (y') is obtained, as indicated in equation (ii) by adding the latest time value (Δx) to the *sum* of all the previous values. This summation of previous values is symbolized by τ in equation (ii).

Second Case.—(Fig. 19). The dotted line, c - d, being drawn tangent to the point E, we have, by similar triangles.

$$\frac{dy}{dx} = \frac{y}{xd} \qquad (cc)$$

just as in equation (c). In this case, however, we observe that the symbol dy represents a *diminution* of speed, because y is greater than y', and, consequently, if we applied equation (b) we would have

$$y' - y = -dy \qquad (n)$$

since $y = y' + dy$.

Hence, equation (cc) should be written

$$-\frac{dy}{dx} = -\frac{y}{xd} = -k \qquad (n)$$

and we have, by analogy to equation (e)

$$dx = -dy \times \frac{1}{k} \qquad (o)$$

and by analogy to equation (i),

$$\Delta x = -\Delta y \times \frac{1}{k} \qquad (p)$$

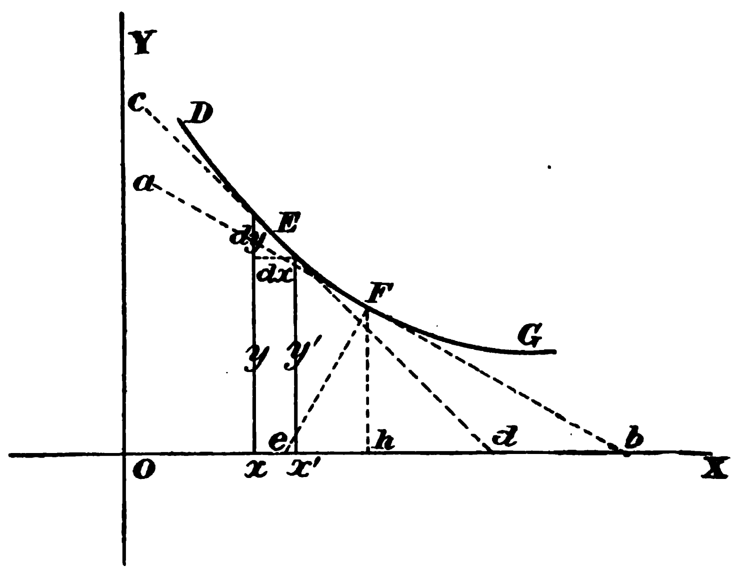


FIG. 19.

or the successive time increments, Δx, correspond to descending speed values ($-\Delta y$), in the curve.

In this case as in the first case, there will be an error, if the wrong differential coefficient is used in applying equation (p). This error has, however, a slightly different expression, resulting from the negative sign in (p).

Using the same notation as before, we have

$$\Delta x^{\pm} = \Delta x' - \Delta x''$$

$$= -\frac{\Delta y}{k}\left(-\frac{-\Delta y}{k''}\right)$$

$$= \frac{\Delta y}{k''} - \frac{\Delta y}{k'}$$

$$= \Delta y \left(\frac{k' - k''}{k'' \, k'} \right) \qquad (q)$$

In this case a positive sign for $\Delta x^{\pm}$ will mean that the incorrect value ($\Delta x''$) is too large, and must be reduced by an amount equal to $\Delta x^{\pm}$. Since the general form of equation (q) is the same as that of equation (1), the remarks already made concerning the proportionality of the error will also apply to this case.

The practical significance and application of the foregoing analysis and reasoning are as follows:

Accuracy in plotting speed-time curves requires that:

First.—The speed points should not be taken too far apart (or the speed differences should not be taken too great).

Second.—The " flatter " the curve (or the smaller the rate of acceleration), the smaller the speed differences ought to be.

Third.—For high accelerations (corresponding to the lower portions of acceleration curves), the speed differences may be taken from 1 mile per hour to 10 miles per hour, or even higher, according to the degree of precision required.

Fourth.—For low accelerations the speed differences must be gradually reduced as the rate of acceleration decreases (as in the flat parts of acceleration curves), until it amounts to a small fraction of a mile per hour—from five-tenths to one-tenth or less, according to the degree of precision required.

Fifth.—The speed increment (Δy) should be reduced whenever it gives by equation (i) a too high time increment value (Δx). The time value may be considered high when it exceeds two seconds for high accelerations, five seconds for medium accelerations, and ten seconds for low accelerations. For very accurate work, the limits ought to be set considerably lower, or one-half second for high accelerations, two seconds for medium accelerations, and five seconds for low accelerations.

These observations have been verified and confirmed by practical experience.

APPENDIX D.

Brake Curve Problems.

To plot any portion of a braking curve which follows or which is assumed to follow a straight line, we only need to determine the coördinates of the first and last points of the said portion of curve.

The three following "problems" show how the coördinates may be determined in different cases.

Problem I.—At what speed point must the brakes be applied in order to bring the car to a stop at an exact given point, the rate of retardation being constant and known or assumed.

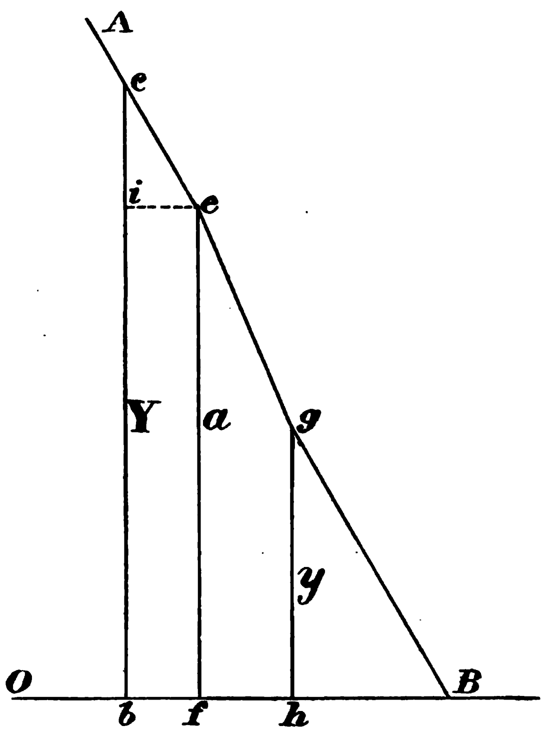


Fig. 20.

This problem is the same as that of finding the point *g* in Fig. 20.

Let ordinates (y) represent speeds (m.p.h.)

Let abscissæ (x) represent time (seconds)

Let s = distance, in miles.

Let A = area, (m.p.h. seconds).

It has been shown in Appendix A (Equation *e*), that the area of any portion of a speed-time curve is equal to a distance.

In this case the rate of retardation being assumed constant, and the speed-line being consequently straight, the area of the portion considered ($h\ g\ B$), is the area of a right-angled triangle, which, it is well-known, is equal to

$$A = \frac{y\,x}{2} \qquad (a)$$

In this case the value of x is not given. We can obtain it however, from the rate of retardation

$$\frac{dy}{dx} = k$$

Since k is assumed constant, we may write $y + x = k$ whence

$$x = \frac{y}{k} \qquad (b)$$

Substituting this value in (a) we have

$$A = \frac{y^2}{2\,k} \qquad (c)$$

The speeds being taken in miles per hour, and the time values in seconds, the area value will be expressed in m.p.h. seconds. A train moving with a velocity of one mile per hour for one hour would cover a distance of exactlv one mile. There being 3,600 seconds in one hour, it follows that 3,600 mile-seconds *of area* are equivalent to one mile of *distance*. Hence, dividing the area A by 3,600, we have distance s in miles, or

$$s = \frac{A}{3{,}600} = \frac{y^2}{2\,k\;3{,}600} = \frac{y^2}{7{,}200\,k} \qquad (d)$$

from which, solving for y, we have

$$y^2 = 7{,}200\,k\,s$$
$$y = \sqrt{7{,}200\,k\,s} \qquad (e)$$

which is the speed point " g " in Fig. 20

The time value (x) will be (from equation b),

$$x = \frac{y}{k} = \frac{\sqrt{7{,}200\,k\,s}}{k} \qquad (f)$$

Problem 2.—At what speed must braking begin in order to travel a specific distance, and still have a certain definite speed, at the end of said distance, the rate of retardation being constant and known or assumed?

This problem may also be stated as follows:

Given the speed value (e) which a car must still have after having passed over a given distance while being braked, and under a constant given rate of retardation, to find the initial speed value (c) at which the braking must begin.

The area of the portion of curve under consideration (b, c, e, f), is equal to the mean of the ordinates multiplied by the abscissa, or

$$A = \frac{(Y+a)\,x}{2} = (Y+a)\,\frac{x}{2} \tag{g}$$

The value of x is obtained, as in the previous problem by reference to the rate of retardation

$$\frac{dy}{dx} = k \tag{h}$$

This equation, it is evident, applies only to the upper or triangular portion, $i\ c\ e$, of the whole area. Hence, the value of y, as given in equation (b) must be taken to mean, in this case, that portion of y' which is above the point i. This portion is

$$y = Y - a$$

which value, substituted for y in equation (b) gives

$$x = \frac{Y-a}{k} \tag{i}$$

This value, substituted in equation (g) gives

$$A = \frac{(Y+a)\,(Y-a)}{2\,k}$$

$$= \frac{Y^2 - a^2}{2\,k} \tag{j}$$

Dividing by 3,600, as before, we have

$$s = \frac{A}{3{,}600} = \frac{Y^2 - a^2}{7{,}200\,k} \tag{k}$$

whence, solving for Y,

$$Y^2 = 7{,}200\,k\,s + a^2$$

$$Y = \sqrt{7{,}200\,k\,s + a^2} \tag{l}$$

The value of Y is the speed at the point c in the curve.

Problem 3.—What will be the distance covered when braking for the purpose of reducing the speed from a given initial value to a given final value, the rate of retardation being constant and being known or assumed?

The solution of this problem is easily obtained by solving for s, in equation (l) of Problem 2. The solution gives:

$$s = \frac{Y^2 - a^2}{7{,}200\ k} \qquad (m)$$

which is the same as equation (k).

(Note.—In all three of the preceding Problems, k is the resultant retardation, and its value is to be obtained according to the formula in equation (X) given in Section II of the paper.)

APPENDIX E.

Use of Metric System.

When the metric system of measurement is used, the formulæ and the methods of plotting mentioned in this paper will still apply if modified so as to make due allowance for the difference between the metric and English units employed for measuring distance, speed, and weight.

The usual practice, in all countries where the metric system is in use, is to measure train speed or car speed, (*i. e.*, " *amount* of velocity) in " kilometres per hour," a term of measure analogous to our term " miles per hour." The logical term or unit of measure for acceleration (*i. e.*, *rate* of velocity), or for the quantity termed the " acceleration coefficient " in the paper, would be " kilometres per hour " *per second*, which would be analogous to our term " miles per hour " *per second*. For some reason, however, this unit does not seem to be much used, if at all. The unit of acceleration generally used by European engineers is the " *metre per second per second*," which is analogous to our " foot per second per second." It certainly would be more logical and less confusing to express both *amount* and *rate* of velocity in like terms, using either *kilometres per hour* only, or *metres per second* only, for the *amount*, and the same unit *per second*, for the *rate* of velocity, (acceleration coefficient).

Train weights, according to the usual practice, when using the metric system, are expressed in metric tons (2,204.6 lbs.).

Time values are expressed in seconds, minutes or hours, just as in the English system.

The following table gives, for both systems, the corresponding values of certain quantities which enter in the equations employed in the paper:

WEIGHT.

METRIC UNIT.		ENGLISH UNIT.
1 Kilogram	=	2.2046 lbs.
0.4536 kilogram	=	1.0 "
1 ton	=	1.1023 ton of 2000 lbs.
0.9072 ton	=	1.0 " " " "

DISTANCE.

1 metre	=	3.281 ft.
0.3048 metre	=	1.0 ft.
1 kilometre	=	3281 ft.
" "	=	0.6214 mile.
1.609 "	=	1.0 "

VELOCITY.

1 metre per second	=	3.281 ft. per second.
1 " " "	=	2.24 miles per hour.
1 " " " =.36 kilometres per hour.		
0.305 metre per second	=	1 ft. per second.
0.447 " " "	=	1 mile per hour.
1 kilometre per hour	=	0.621 mile per hour.

ACCELERATION.

1 meter per second per second = 1 "A" unit of acceleration.	=	2.24 m.p.h. per sec.
1 kilometre per hour per second = 1 "a" unit of acceleration.	=	0.621 m.p.h. per sec.
0.447 "A" unit	=	1.0 m.p.h. per sec.
1.609 "a" "	=	" " " "
1 "A" unit. = 3.6 "a units.		
1 "a" " = 0.278 "A" "		

We now proceed to investigate the effect of these changes in numerical value on the equations given in the paper.

Appendix A.—The same equations will all apply without change. If distance (s) is expressed in metres, and time in seconds, then velocity (v) will be expressed in " metres per second." If distance is expressed in " kilometres " and time in hours, velocity will be expressed in " kilometres per hour."

Appendix B.—Equations (1) to (16) will apply without change, the symbols v, s, g, w, being taken in suitable metric units. All the other equations require modification.

In Equation 1a, when energy (E) is expressed in kilogram-metres, and distance (s) is expressed in metres, force (F) will be measured in kilograms of (pushing or pulling) effort.

The metric value of g being taken as 9.81 (metres per second) and w being taken in kilograms, we will have for equation (17), and using the letter "*m*" as a distinguishing sign for "metric" equations,

$$M = \frac{w}{g} = \frac{w}{9.81} = .102\,w \qquad m(17$$

and for equation (18*a*)

$$A = \frac{F}{.102w} = \frac{F}{w}\,9.81 \qquad m(18a)$$

the force, F, being expressed in *kilograms* (not *dynes*) of effort. Thus, when the force (F) and the weight acted upon (w) arc both equal to 1 kilogram (as in the case of a body falling vertically, in vacuo), the rate of acceleration will be 9.81 metres per second, per second. If the weight of a train, w, is to be expressed in metric tons, we will have

$$w = 1{,}000\,W$$

where w = weight in kilograms,
and W = " " tons of 1,000 kilograms.

Substituting for w, in equation 18*a*, we have

$$A = \frac{9.81\,F}{1{,}000\,W} = .00981\,\frac{F}{W} \qquad m(18b)$$

This equation may be used instead of equation 21*a*, if velocity is to be expressed as a space-rate *per second* instead of *per hour*. To transform the equation into one expressing acceleration in kilometres per hour per second, we note from the preceding table of equivalents that

1 metre per second = 3.6 kilometres per hour.

Hence, equation (19) becomes

$$3.6A = a$$

whence

$$A = \frac{a}{3.6} \qquad m(19)$$

Substituting in equation 18*b*, we have the equivalent form of equation 21*a*, or

$$\frac{a}{3.6} = .00981 \frac{F}{W}$$

whence,

$$a = .03532 \frac{F}{W} \qquad m(21a)$$

The values of F and W will, of course, depend on whether acceleration is to be expressed in terms of " A " or of " a."

Solving for F, we will have, from equation m (18*b*)

$$F = \frac{W\,A}{.00981} = 101.94\;W\,A \qquad m(22a)$$

and, from equation $m(21a)$,

$$F = \frac{W\,a}{.03532} = 28.31\;Wa, \qquad m(22)$$

Solving for W we will have, from equation $m(18b)$,

$$W = .00981 \frac{F}{A}\;; \qquad m(23a)$$

and, from equation $m(21a)$

$$W = .03532 \frac{F}{a} \qquad m(23)$$

Equation (24) remains unchanged, but the numerical value of P will evidently depend upon whether the value of F be taken from equation $m(22a)$ or from equation $m(22)$; in other words, it will depend upon the unit of acceleration assumed (whether " A " or " a ").

Equations (25, 25*a* and 26) will retain the same form, the constant 91.1 being, of course, replaced by either of the corresponding metric constants given in equations $m(22a)$ or $m(22)$, according to the unit of acceleration adopted.

The last three equations will also retain the same form, and the values obtained for A' will likewise depend upon the unit of acceleration adopted.

The time-rate of velocity " k " will evidently have a different numerical value according to the unit of acceleration used.

Equation $m(19)$ shows that its numerical value will be 3.6 greater when acceleration is expressed in kilometres per hour per second ("a" units), than when it is expressed in metres per second per second ("A" units.")

Appendix C.—All the equations retain the same form. The numerical values obtained by means of the various formulæ will obviously depend upon the units of speed and acceleration adopted, since these govern the values of the speed increments (Δy) and of the acceleration coefficients (k).

Appendix D.—When velocity (y) is expressed in ***kilometres per hour***, the equations will all retain the same form. Distances will then be measured in kilometres, the values taken for k being those obtained by reference to equation $m(21a)$. When velocity is expressed in ***metres per second***, the constant 3,600 disappears from equations (d) (e) (f) (k) (l) (m). Distances will then be measured in metres, the values taken for k being those obtained by reference to equation $m(18b)$.

The modified forms of these equations (which, it should be carefully noted, apply only when acceleration is measured in "A" units), will be:

$$s = \frac{y^2}{2k} \qquad m(d)$$

$$K = \sqrt{2ks} \qquad m(e)$$

$$x = \frac{\sqrt{2ks}}{k} \qquad m(f)$$

$$s = \frac{Y^2 - a^2}{2k} \qquad m(k)$$

$$y = \sqrt{2ks + a^2} \qquad m(l)$$

$$s = \frac{y^2 - a^2}{2k} \qquad m(m)$$

Specific Equations.—The equations (I.) to (XII.) inclusive, contained in the body of the paper are mostly derived or adapted from the general equations given in the appendix sections A, B, C, D, of the paper.

The following tables give, in parallel columns, the modifie forms of each of these equations, when adapted for the metr' system:

TABLE III.—(APPENDIX E.)

No.	First Term same for All.	Last Term of Equation. As Given in the Paper.	Modified for Metric System. For "A" Units.	For "a" Units.
I	$\frac{dv}{dt}$	$= k \pm k' \pm k'' \pm$ etc.	same	same
II	F	$= .01098 \frac{F}{W}$	$= .00981 \frac{F}{W}$	$= .03533 \frac{F}{W}$
III	A'	$= \frac{.01098}{W} (p \pm p' \pm$ etc.)	$= \frac{.00981}{W} (p \pm$ etc.)	$= \frac{.03542}{W} (p \pm$ etc.)
IV	A'	$= .01098 (p \pm p' \pm$ etc.)	$= .00981 (p \pm$ etc)	$= .03532 (p \pm$ etc.)
V	A'	$= .01098 (p - f - c \pm G)$	$= .00981 (P - f - c \pm G)$	$= .03532 (P -$ etc)
VI	p	$= P - f - c \pm G$	same	same
VII	$-A'$	$= .01098 (-f - c \pm G)$	$= .00981 (-f - c \pm G)$	$= .03532 (-f - c \pm G)$
VIII	$-A'$	$= -.01098 f$	$= -.00981 f$	$= -.03532 f$
IX	$-A'$	$= -.0198 (-B - f - c \pm G)$	$= -.00981 (-B -$ etc.)	$= -.03532 (-B -$ etc.)
X	$-A'$	$= -1.647 \pm (.01098\ G)$	$= -.731 \pm (.00981\ G)$	$= -2.65 \pm (.03532\ G)$
XI	N	$= \frac{20}{b}$	$= \frac{22.04}{b'*}$	$= \frac{22.04}{b'*}$
XII	G	$= \frac{N b}{20} = .05\ N b$	$= \frac{N b}{22} = .045\ N b$	same

*Where b' = increased train resistance in kilograms per degree of track curvature

Metric Curve Plotting.—The methods of curve plotting described in the paper can also be employed in plotting " metric " speed-time curves. In using the Chart Method, however, special " metric " charts of Acceleration Coefficients and of Reciprocals will be required; and these charts will have to be prepared with special reference to the particular unit of acceleration employed.

Chart of Coefficients.—If acceleration is to be measured in " A " units (*i. e.*, in metres per second per second), the ordinates in the chart of coefficients will represent values of the acceleration coefficients such as determined by equation $m(18b)$, and the abscissæ will represent speeds, expressed in metres per second. If acceleration is to be measured in " a " units (*i. e.*, in kilometres per hour per second), the ordinates will represent values of the acceleration coefficients such as determined by equation $m(21a)$;

and the abscissæ will represent speeds expressed in kilometres per hour.

If the Chart of Coefficients is to have approximately the same range as the Chart shown in Fig. 9, the scales must be approximately as follows: For " A " units of acceleration, the scale of coefficients (ordinates) must read to about 1.2 metres per second per second, and the scale of abscissæ must read to about 32 metres per second; for " a " units of acceleration, the scale of ordinates must read to about 4.0 kilometres per hour per second; and the scale of abscissæ must read to about 115 kilometres per hour. The scale divisions should obviously be larger in the Chart for " A " units than in the Chart for " a " units.

The gradient percentage lines will be straight just as they are in Fig. 9, but their distances from the axis of x will be different in the two cases. A grade of 1 per cent. will represent a force (F) of 10 kilograms per ton, in both cases; but the numerical value of the acceleration produced by this effort will depend upon the unit of acceleration used. In " A " units, we would have by equation $m(18b)$,

$$A = .00981 \times 10 = .0981 \text{ metres per second per second.}$$

and, in " a " units, we would have, by equation $m(21a)$,

$$a = .03532 \times 10 = .3532 \text{ km. per hour per second.}$$

This means that the scale of gradient percentages at the right hand end of the Chart would be such that the line of equivalent acceleration for a 1% grade would be distant from the axis of x by an amount equal, respectively, to .0981 metre per second per second for " A " units, and to 0.3532 km. per hour per second for " a " units, when measured on the scale of acceleration coefficients at the left-hand end of the Chart. The corresponding line for a gradient of n per cent. would obviously be placed at n times the said distance.

Chart of Reciprocals.—The scale of ordinates in the Chart of Reciprocals will be the same as in the Chart of Coefficients, for reasons explained in the paper. The scale of abscissæ may be made as desired. The scale being arbitrary, it may be the same for the Charts of Reciprocals used for both " A " and " a " units.

Use of Charts.—The process of plotting " metric " speed time curves by means of the Metric Charts just described, is substantially the same as indicated in the paper for plotting curves by means of the Charts shown in Figs. 9 and 10.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers Great Barrington, Mass., June 19th 1902

NEW ELECTRO-PNEUMATIC SYSTEM OF ELECTRIC RAILWAY CONSTRUCTION.

BY BION J. ARNOLD.

During the past three years, as many of the members of the INSTITUTE know, I have advocated the use of the alternating current motor for certain classes of railway work somewhat earnestly, and have often been asked by my friends why I believed so thoroughly in the alternating current motor, and have been questioned rather closely at times for particulars regarding a certain system which I have been working upon.

I wish to state that long before I had any fixed ideas as to a system of my own, a study of the railway question from an engineering standpoint partially convinced me of the necessity of the ultimate abandonment of the direct current motor for heavy and long-distance service, due to the low working voltage to which it was necessarily limited, the resulting heavy investment in transmission lines thereby required, and the many translations between the power station and the car when any great distance was taken into account.

An active connection with the development and construction of electric railways in this country impressed me with the correctness of my preconceived ideas to such an extent that they finally crystallized into a system of electric railway construction upon which I have been working for several years, and to which I have alluded from time to time without giving, to those not interested with me, any definite information regarding it, for reasons well-known to those working upon new devices.

I have constructed twenty miles of road for this system, together with the necessary trucks and motor equipments, and as I am reasonably sure of the interest you will take in this system, I feel warranted in presenting it to this INSTITUTE.

As I have previously stated before the INSTITUTE, I am particularly anxious that American engineers shall keep abreast with European practice in the development of the alternating current electric railway, and while some of my brother engineers may not agree as to the practicability of my ideas, there are others in the INSTITUTE who, I think, believe as thoroughly as I do in the alternating current motor for railway work, and whether my system proves the correct solution of the question or not, I firmly believe that the alternating current motor will finally prevail for heavy railway work.

The recent discussions of this question that have been going on between engineers in Europe and the United States have made the subject a live one at present, and this is my reason for presenting a brief description of one embodiment of my system at this meeting.

The principles underlying the system which I advocate and which I call an Electro Pneumatic System, are as follows:

1st.—A single-phase or multiphase motor, mounted directly upon the car, designed for the average power required by the car, and running continuously at a constant speed and a constant load, and, therefore, at maximum efficiency.

2d.—Instead of stopping and starting this motor and dissipating the energy through resistances, as is customary with all other systems known to me, I control the speed of the car by retarding or accelerating the parts usually known as the rotor and stator of the motor, by means of compressed air, in such a manner that I save a portion of the energy which is ordinarily dissipated through resistances, and store it to assist in starting the car, helping over grades, for use in switching purposes, and for the operation of the brakes.

3d.—By this method of control I secure an infinite number of speeds from zero to the maximum speed of the car, which may or may not be at the synchronous speed of the motor, for with the air-controlling mechanism working compressing, the speeds below synchronism are maintained, and by reversing the direction of the air through the controller speeds, above synchronism may be attained for reasonable distances. This feature gives to the alternating current motor the element absolutely essential for practical railway work, for it permits a car or train to ascend a grade at any speed with the motor working at its maximum efficiency, and imparting its full power to the car. When descending the grade, the motor may utilize its full power drawn from the line in compressing air, or it may be used to compress air with the stored energy of the train, thereby acting as a brake.

4th.—By virtue of the air storage feature, each car becomes an independent unit and is capable, in case of loss of current from the line, of running a reasonable distance without contact with the working conductor, and this without the aid of storage batteries. This feature will enable a car to work on a high tension trolley wire or active conductor over private right of way, and allow the active conductor to be stopped where the private right of way ceases, and the car to proceed through a city or town on any tracks, whether electrically equipped or not, until it reaches the outskirts of the city or town where it can take up the working conductor again on private right of way. This feature is also valuable in switching work, for each car being independent it may leave the main line track and operate over switches or sidings without complicating the yards with additional overhead or third rail conductors, thus necessitating through line conductors over main line track or tracks only.

5th.—Since a single phase motor can be used, the motors can be supplied with current from a single overhead wire or third rail, and with a single rail return circuit, thus permitting the overhead construction, or third rail construction, to conform to the standard of to-day, except that a much higher working voltage can be used, provided the insulation is taken care of. Furthermore, in steam railway work, this system by virtue of its single phase feature, will require the use of only one of the track rails for the return circuit, thus leaving the other rail for the use of the signal system, which, up to the present time, does not seem to have been satisfactorily solved without the use of one of the track rails.

6th.—The current will be taken from the working conductor at any voltage up to the limit of the insulation, and in case this voltage is high (I am building my line for 15,000 volts), a static transformer will be carried upon each car and the pressure reduced from the line voltage to the voltage of the motor, which in the case under construction is designed to be 200 volts. Where it is unnecessary to utilize so high a line pressure, the motor may be designed for the working voltage, and the current fed directly from the working conductor into the motor, thus eliminating the static transformer. When a high voltage working conductor and static transformer is used, and it is thought advisable to use a working conductor through cities or towns, this working conductor will be supplied with energy through a stationary transformer at each city limit, thus making the working conductor through the cities or towns safe.

7th.—By virtue of the speed of the motor and its constant load, either when the car is in motion or when it is standing still and the motor is compressing air, the variable load now customary in electric railway power plants is eliminated, and the power station works at practically a constant load, thereby eliminating a large part of the investment at present requisite in power station and line construction. Furthermore, by virtue of the air storage feature, each car, in the particular apparatus I have designed, is capable at any time when current is on the working conductor, of delivering to the car wheels a much greater torque in proportion to the capacity of the motor than is possible with any electrical system known to-day.

I believe that by the adoption of this system the following results will be accomplished:

1st.—The entire elimination of the present standard system of rotary converter sub-station plant, together with the maintenance thereof, and the cost of the necessary attendants.

2d.—The absorbing and rendering available for useful work in starting, or otherwise, of a large percentage of the energy stored in the moving mass which under the present methods of operation is dissipated at the brake shoes.

3d.—A large reduction in the first cost of electrically equipping long-distance railroads, thereby making it feasible, from an engineering and business standpoint, to equip many roads which cannot now be shown to be advisable, thus opening up the steam railway field to the industry in which we are now engaged.

Discussion.

Papers by A. H. Armstrong, W. B. Potter and B. J. Arnold, and by C. O. Mailloux, and B. J. Arnold, at Great Barrington, Mass., June 19, 1902.

Dr. Perrine:—I have received a telegram from the Pacific Coast Transmission Association to the American Institute of Electrical Engineers. They are in meeting at this time. It refers particularly to the underwriters' rule that was proposed, that constant tension lines of over 3,500 volts should not be installed within 75 feet of a building; and the enforcement of that rule would probably kill transmission lines. We are all interested in the rule, and we have a committee to consider it. It is very vital, and consequently they have telegraphed me as follows:

"Transmission convention to-day unanimously adopted resolutions condemning enactment of proposed restriction of overhead line voltages as unwarranted, unjustifiable and eminently prejudical to vested interests and appointing you commissioner to present same to Institute."

President Steinmetz:—Referring to the telegram which has just come to us through Dr. Perrine, I believe it is proper to refer this matter to the Committee on the National Electric Code, which is a special committee of the Institute. That it be instructed to consider it and give expression of the feeling of the Board of Directors against such proposed rules. Now, I believe we can leave the matter in Dr. Perrine's hands, because Dr. Perrine is a member of this committee.

Secretary Pope then presented to the Convention and read the following letter:

Berlin, June 9, 1902.

Mr. R. W. Pope, Secretary.

Dear Sir:—Present to the Institute my most sincere regrets that I am unable to be present. I trust that the Great Barrington meeting may be most successful and may give the Institute an impetus for the coming year.

Let every one determine to do his part in continuing the excellent work of the past year under President Steinmetz, and making the Institute a more effective factor in the progress of American electrical engineering.

Most sincerely,
Chas. F. Scott.

President Steinmetz:—There being no further announcements, discussion is now in order. We should all be very delighted to hear Mr. Sprague open the discussion, than whom nobody is more able, more willing and more apt to lead on this topic, to which he has not only given attention, but with which he has been living since the early days of electrical railroading.

DISCUSSION.

MR. F. J. SPRAGUE:—Mr. President and Members: I had not intended to take part in the discussion to-day, and for certain reasons would prefer to remain in the background. The paper which has been read by Mr. Arnold is, however, of such importance that I think that I may personally, and for the INSTITUTE, express our appreciation of what is one of the most important communications which will be presented at this meeting. This is so not only because of the character of the paper itself, but because it deals with a problem the solution of which is very urgent, and is, moreover, of special interest to those who live in, or who come to New York. If not arriving by way of the ferries and the railways connecting therewith, the passenger must come over the New York Central, Harlem or New Haven roads, and is thereby confronted with the necessity of entering New York through a tunnel which, at the present moment at least, does not offer much in the way of attraction. Mr. Arnold's paper is, I believe, an abbreviation from reports made by him to the New York Central Railroad Company from time to time, and deals with the general possibility of electric operation and the relative economies of steam and electric motive power for the terminal service between Mott Haven and the Grand Central Station. Perhaps it is inexpedient for Mr. Arnold, under existing circumstances to say much more, or to discuss other phases of the problem.

The subject is one to which I have given considerable attention, and I am glad to note that the power requirements agree very closely, considering the changed conditions, with the result of a similar investigation made under my direction some three years ago. Mr. Arnold has very wisely confined himself to the problem of train movements within the limits of New York City, instead of complicating his report and confusing his clients by speculations as to the possibilities of through electric service, the methods for accomplishing which are still, and for some time are likely to be, matters of discussion and probable disagreement among the ablest engineers. For the specified service, the use of continuous current motors, to be operated at a moderate pressure, is a safe, and the only safe recommendation. The paper makes a special comparison of steam and electric operation in the matter of economy, with the result that no special advantage is shown in favor of one or the other. Economy, however, is in this particular case the least important consideration, and I do not doubt that Mr. Arnold believes with me that while this comparison is necessary, there is no question, not only as to the practical possibility of electric operation, but of its wisdom and even imperative need on the score of comfort and safety, despite recent somewhat pessimistic assertions to the contrary; and, furthermore, that the financial results would also entirely justify the change. On account of the special nature of the problem, if the railway company defers the adoption of electricity until some great saving in car-mile operation is manifest, steam will continue for a long time to be the motive power in the tunnel. Safety, cleanliness, and comfort, however, being assured, increased earnings will most assuredly result from increased traffic.

The problem is a two-fold one—the replacing of the steam locomotive on through trains at some point above Mott Haven, and the operation of the suburban service, at first possibly by replacing the steam locomotives within a given zone, and later by the complete adoption of electricity within twenty or thirty miles of New York. The requirements have to be met in different ways. At present both train services are operated by steam locomotives. The through service must remain such, but the suburban can be readily changed. No less than ten or a dozen types and sizes of locomotives are now in use, pulling at limited speeds trains varying in weight from 150 to 600 or 700 tons. It would seem, therefore, that so far as locomotive service is concerned, it can be best performed by units of ,say, 30 to 35 tons weight, and of 700 to 800 h.p., these units to be so equipped and controlled that one may be used for the lighter service, and any two, operated as a single unit, for the heavier. These conditions make imperative what has already been well settled—preferably electrical instead of hand operation of control equipments, and the grouping and simultaneous control of units; in short, the multiple-unit system of operation. For suburban service, individual equipment of cars and like control of any required number is now beyond question.

Another thing must be borne in mind, that is, that electrical equipment not only will ensure greater safety of operation because the tunnel will then be clear of smoke and condensed steam, but the adoption of electrical control will leave the engineer free to devote himself to the safe piloting of his train, untrammelled by the distraction of other duties, the importance of which must be manifest to any one who is familiar with the strain on a locomotive engineer, watching and listening for signals. That the train movements in the tunnel can be effectively made by electrical power must be evident to any unprejudiced investigator, and so far as the possibilities of the case are concerned, I would not hesitate—and I feel sure that I voice the conviction and sentiments of others in the room—to undertake the feat of hauling the heaviest train from Mott Haven to Grand Central Station with electric power on schedule time within six months. Of course, such a demonstration would be a special one and for a single train, for considering the many civil engineering and railway problems involved, from two to three years are necessary to make a general change.

MR. F. S. PEARSON:—Mr. President and Gentlemen:—It gives me pleasure to be here. It is the first meeting of the INSTITUTE that I have been able to attend for seven or eight years. I have little to say for I have been called upon very unexpectedly, and

I am not much of a public speaker, but I have been greatly interested to-day in the papers, as they show the careful and detailed work which is being done on this question of electrical transportation. In Mr. Arnold's paper particularly, I have been impressed with the enormous amount of work that he has been able to do since August, 1901. I am trying to imagine that there were one or two years more between this time and the date on which he said that he commenced his investigation.

MR. B. J. ARNOLD:—The work was done in about four months.

MR. PEARSON:—You must have worked hard—25 hours a day at it. In regard to the remarks of Mr. Sprague, I think that electricity is certain to supplant steam to a very great extent in the next few years, but I look for the greatest development, not in the handling of the long-distance freight traffic, as a great many sanguine engineers are prophesying, but more in the suburban work and in long distance, exceedingly high-speed transportation. The tendency of our race is to hurry. We have just had two 20-hour trains put on between New York and Chicago, and I hope to see 10-hour trains running there within the next ten years; it is perfectly feasible with electricity to do this. With steam, the limits in speed are being well-nigh reached, on account of the limitations of the boiler; but there is no reason, so far as I can see, from the point of safety or as regards power, why we could not make 120 to 150 miles an hour; I think this is the direction in which we electrical engineers will have to work in the next few years. In suburban work, of course, another phase of the question opens up, where an exceedingly high speed is required, but for very short distances; and that is where the great advantage of electricity for suburban work will lie. If we can take a road, 15, 20 or 30 miles in length, with perhaps 10 or 15 stops, and by obtaining a maximum speed of 60 to 100 miles an hour between stops, cut down the average running time to 50 per cent. of what it is to-day on the best steam surface lines, the advantage of our large cities is given to all the suburban public, and this rapid transit is sure to be demanded. The work which Mr. Arnold and Mr. Mailloux have done in the last few months will be of the greatest advantage to all engineers employed in practical development and construction work, who have not the time in most instances to do this detail work, which must necessarily precede construction, and upon which all final results of development must depend. For such careful work as this, which is so practically presented here to-day, the thanks of all engineers are due to those who devote their time so freely to it and so generously present the results to us. I will not take up any more of the time of the INSTITUTE, as I imagine there are others much better able to speak on this subject than I am. I have learned a great deal in the past two days, as in the past years of my membership I have learned from the papers at the meetings where I have not been able to be present.

MR. OBERLIN SMITH:—I think Mr. Pearson is right in saying that the suburban traffic is an entirely separate problem from the high-speed long-distance railroad of the future. I think we must all admit that we cannot safely get these excessively high speeds of 120 to 180 miles an hour with the present form of track. I believe that electrical engineers are ready now to equip cars with transmission and driving apparatus, provided we have a proper roadway. We cannot, however, run upon ordinary tracks laid on the ground and subject to danger by reason of crossings, switches and other obstructions. Furthermore, the cars must be so confined to the track that they can by no means be derailed.

The development of such a railroad is not so difficult an electrical as a mechanical problem, but it is even more of a problem financially. Engineers, electrical, mechanical and civil, are all ready to tackle it and it would not take so very long to build a road and get cars running from Philadelphia to New York in from 30 to 45 minutes at perhaps 5 or 10 minute intervals; but we cannot do this on existing road beds.

The difficulties of financing an undertaking of the kind, especially the first one, will be enormous; and this is what will delay the new movement more than anything else. Possibly by the time that a Hudson River bridge is built, the financiers may be ready to build a roadbed of proper construction. If it is not sunk in the ground it should be elevated (absolutely isolated from all obstructions), and the cars so built that they cannot get off the track—for derailment is the great danger we have to fear. When the cars are mechanically confined and kept where they belong, the roadway and cars forming together a complete and harmonious machine, there is no difficulty whatever, from a mechanical standpoint, in operating them at three miles a minute.

The best place in the whole world to start this grand development of the 20th Century is doubtless between New York and Philadelphia—the only place on earth where two such large cities lie so near together. An experimental beginning might well be made on such part of the complete road as between New York and Newark. The traffic is already enormous, so that there would be no difficulty in getting plenty of passengers. Then, too, the "traveling habit" would enormously increase—with the embodied safety, speed, frequency, cleanliness and perhaps quietness, of the new system. Of course, one great difficulty, besides the mere financing of such a scheme, would be to overcome the opposition of the old roads, and to get proper terminals in places where there are already steam roads in competition.

PRESIDENT STEINMETZ: I see that Mr. Dodd is here. We should like to hear from him.

MR. S. T. DODD:—I have been very much interested in what Mr. Mailloux had to say, but I would not attempt to discuss a paper of that character without having looked into it a good deal more carefully. It has long been an idea of mine that there ought to be some quick easy analytical method by which we could get at a solution of these problems. I have suggested such ideas to Mr. Mailloux once or twice, and his reply to my suggestion has always been that in the particular lines along which I was working it was impossible, and I have always found on further investigation that he was perfectly correct.

PRESIDENT STEINMETZ:—Gentlemen: There is no industry which has been developed as rapidly and to such enormous proportions as electrical railroading, but while this development has been very rapid, more rapid still has been the development of the theory of electrical railroading as shown by the papers presented at to-day's meeting. Now, while a few years ago the theory of electrical railroading consisted in putting any kind of electric motor on any kind of a car, and running it to see what it did, now, you see the speed, the time, etc., calculated with such refinement that engineers are no longer satisfied to assume the constant coefficient of friction, but carefully investigate and bring into the calculation, the variation of the friction with the speed, the momentum of the motor, etc., and succeed in getting simple and accurate results, not only theoretical, but they also gradually gather an enormous amount of experimental data not of the same character as years ago, but based on experiments carefully planned and still more carefully carried out, as shown in Messrs. Arnold and Potter's paper. It is interesting also to see to what refinement the theory gradually develops. The problem was once merely to take a man from one place and put him down in another place, to transport him from a distance. Now, you cannot do that instantly, it takes time; it would be rather uncomfortable to do it instantly; consequently, we have the speed question. Experience shows it would be uncomfortable to go at a uniform speed; to start at one place with full speed, and stop at the other place while at full speed; consequently, we have to consider acceleration; starting and gradually increasing to full speed and then decreasing until the stop. That brings in acceleration. There is one other feature brought out in Messrs. Arnold and Potter's paper: still further refining the matter, we must not start acceleration constantly. In acceleration we have a second differential coefficient of the distance; we must not do that instantly, but gradually increase acceleration to full acceleration, then gradually decrease it again. Then we have to begin to consider the third differential equation of distance, to get a maximum speed with minimum discomfort to the passenger. I look forward to the time when we shall have to consider the fourth and fifth differential. Without joking, it shows how important these things are, because, if by gradually increasing the acceleration we can run at an acceleration of three miles per hour per second, in rapid transit at very high speed—with very frequent stops, it may be the deciding feature of success between the possibility of carrying out the proposition, or the impossibility of carrying it out.

We have not heard yet from the exponents of alternating current railroads. Inasmuch as Mr. Arnold was the strongest advocate of the alternating current railway last year at Buffalo, we would like to hear from him.

MR. ARNOLD:—I have a word to say, but I prefer to say it after the discussion on my present paper is closed, because I have an extemporaneous speech in my pocket, and I want to read it to you.

MR. H. WARD LEONARD:—As some of the members of the INSTITUTE may remember, I suggested about ten years ago, in an INSTITUTE paper, a method of operating a long-distance railway, and it may perhaps be of interest, in connection with the present paper, to note the fact that there is at present under construction by the Oerlikon Works in Switzerland, a locomotive which is exactly such as I suggested at that time. The locomotive is one which will employ a single-phase alternating current, transmitted at about 15,000 volts, with about 75 miles between the power-houses. This single-phase alternating current will be fed to the locomotive and transformed by a motor generator upon the locomotive into a continuous current which will be supplied to the propelling motors upon the axles. The locomotive which is now under construction by the Oerlikon Works will be capable of developing 700 h.p. at the draw-bar, with a tractive effort of about 10,000 pounds at the draw-bar. This I find compares about with Fig. 12 of Mr. Arnold's paper. The weight of the locomotive will be about 44 tons. Of course, all its weight will be upon the drivers. This also corresponds quite well with Fig. 12 of Mr. Arnold's paper, in which 45 tons is upon the drivers. It is expected by the Oerlikon Company that the efficiency of this locomotive will be about 75 per cent. The cost of the conductors, on account of the high voltage, will be comparatively low, being estimated at about $1,200 per mile. The advantageous features of this system are that there are no idle resistances used and there is no opening of heavy currents. The generator has a separately excited field and also the motors, and the variation of speed is accomplished by the variation of the voltage produced by the generator and supplied to the motor armatures, which are operating in constant separately-excited fields. This makes it possible to accelerate the load without any jerks, and it will accomplish that which is so much desired, and which Mr. Steinmetz has referred to; that is, an increase in the rate of acceleration, which will be very decidedly preferable as regards the comfort of the passengers and as regards strain upon the draw-bar and transmitting mechanism. The restoration of energy by this system in stopping and upon down grades is perfect, and the restoration of energy may be made efficiently, not merely while the locomotive is at full speed but at any speed and at all speeds down to dead rest. The size of the motor generator and its weight are factors of importance, and by many have been considered as fatal to the introduction of the system, but the economies and perfection of control which result from this variable speed ratio of electrical gearing are such that it has many advantages that may perhaps overcome the disadvantages that the motor generator gives. It may also be of interest for me to say that I have recently brought out and patented a system of multiple control which is adapted to this particular form of electric railway system, by which it will be possible to couple and control in a very simple manner any number of locomotive units from any desired point on the train and without the necessity of opening any motor circuits or having any resistance or automatic switches in the motor current. An advantage that this system will give, which is not so well reached with other systems, is a very perfect distribution of the tractive efforts at the various driving wheels, without any skidding difficulties such as are likely to result in the case of a series motor. There are a good many incidental advantages in connection with this system that are minor, but as this locomotive is now under construction and is likely to see service in the immediate future, the only thing I wish to call attention to now is the fact that results will be probably available from practice with this system shortly.

MR. HARRY ALEXANDER:—I would like to ask Mr. Arnold a question. I have in mind a mental photograph of the yards south of 56th street on the New York Central road. Has he got to the point where he has under consideration the breaking of the overhead construction line, owing to the multiplicity of tracks and the breaking of the circuit while the train is still under enormous starting currents? That is a problem of minor degree, but still of great importance.

MR. ARNOLD:—We do not break the current at all; we are supposed to have a continuous plate overhead in the yards.

MR. ALEXANDER:—I do not see how that is possible with all the crossings there, at each of which there must be a break in contact.

MR. ARNOLD:—Simply an upper-bearing contact shoe bearing against a continuous plate conductor.

MR. ALEXANDER:—You have a break on the surface third rails or conductor rails, at all rail crossings, and there must be a break of *contact* to some extent at least, even if the break in the conductor is bridged by a contact plate.

MR. ARNOLD:—When the working conductor is on the ground it is necessary to break it only to let the track rails through at switches and cross-overs, but I do not see the necessity of a break in the overhead rails; the working conductor is overhead and as there are no track rails overhead there is nothing in the way to prevent a continuous contact of the under running shoe.

MR. A. H. ARMSTRONG:—I do not want in any way to forestall the extemporaneous paper which Mr. Arnold has in his pocket; I know he is going to deliver it and that it is well worth listening to, but the subject of alternating motors has been brought up and I want to discuss two or three points in connection with such motors. We are all interested in long-distance high-speed travel and have lately read in periodicals some partial results of very complete experiments made in Germany where the maximum speed reached 100 m.p.h. with single electric cars. The results of these experiments would seem to indicate that such work may be taken up by the electrical engineer with perfect assurance of success, provided, as has already been touched upon in this meeting, that a roadbed with sufficient carrying capacity is furnished. In fact, the problem becomes not an electrical one but rather one of mechanics, the providing of a car of sufficiently strong construction, wheels that will not fly to pieces at the speed contemplated, and, more than all, the providing of a roadbed capable of sustaining the tremendous shocks which a car at these high speeds is bound to deliver. All this has a bearing upon the subject of alternating railway motors. Very high speeds would hardly be contemplated for short distances, except, as Mr. Pearson pointed out, that such high maximum speeds might be used to reduce the running time on suburban systems where the traffic was enormous and where the running time between terminals was the all-essential point. High-speed roads, however, are essentially long-distance roads. Direct current is limited in the distance to which it can be transmitted economically, and a direct current generating station could not be considered for roads of this character. The problem thus necessitates consideration of alternating current either single-phase or multi-phase, and either converted to direct current or used with some form of alternating motor placed on the moving car. If alternating motors are used, the single phase is preferable and may or may not be of the ordinary induction type. The primary consideration is, however, the installation of some form of alternating motor upon the car, receiving alternating current over the trolley or third rail at potentials much higher than used at present, say 3,000 volts or even as high as 10,000 volts. As any further remarks that I have to make in this direction are of secondary importance to the bringing out of Mr. Arnold's paper, I resign the floor in his favor.

Mr. Potter:—As the paper which Mr. Arnold and I prepared relates particularly to the relative performances of the steam locomotive and motor car, I think in closing the discussion it might be well to point out, or rather to emphasize, the advantage of eliminating the dead weight of the locomotive in the consideration of apparatus for high-speed work, particularly the use of alternating current apparatus. It would seem to be specially advantageous that each car should carry by itself as little apparatus as possible. While beyond doubt single-phase current, transformed into polyphase or into direct current, would operate an electric locomotive of any form economically and would probably perform its service well, there would seem to be a decided advantage, where alternating line current was to be used, that there should be as little motive power apparatus on the locomotive as possible other than the motors themselves, this applying equally whether the motors themselves are alternating or direct current. We have doubtless all looked forward to a single phase railway motor having the characteristic of the direct current series motor and operated from a single trolley, and I trust that study and development will ultimately produce such an equipment, but at present there is no simple and satisfactory motor or method of control. Three-phase railway motors have been and may readily be used, with certain limitations, but it seems hardly probable that the development of the art in connection with polyphase transmission will be other than the use of the least amount of apparatus that can be installed upon the car for the purpose.

There is one limitation that we must take into consideration. I have heard it stated that our standard gauge of 4 feet 8½ inches was established by a blacksmith in Albany, who was told to cut a 5-foot gauge for the Mohawk Railroad, but his rule slipped or something happened and he cut the bar 4 feet 8½ inches, and I believe that is the basis of our standard. It would well have served our purposes if he had cut it 6 feet long. The space provided between the wheels on the standard gauge does not afford the same possibilities in designing motors for installation on a car as for stationary use. In stationary apparatus we do not care whether a motor is just so many inches high or wide, whereas in designing a railway motor, of whatever type, very frequently in order to secure another eighth of an inch in clearance a complete redesigning of all the parts is necessary; we cannot change one element without changing many, so closely are the details laid out. The diameter of wheel, diameter of axle and length of wheel-base, all have an important bearing on the motor design. In this country there is a disposition to favor a short wheel-base. High speeds and the carrying of motors directly on the axle, require an axle of larger diameter than are commonly used on passenger coaches. That of itself takes part of the space, and I think it is a very serious handicap in the development of motors for railway work, that the wheel-base should be so generally limited to 6 feet. For motors of 100 h.p. or over, it is very desirable that the wheel-base should be at least 6½ feet. A 36-inch wheel would also be advantageous. A 6-foot wheel-base truck, does not permit the best design of motor of any character in large sizes nor does it allow the space for axle diameter and truck bolster that should be provided for heavy service.

PRESIDENT STEINMETZ:—Gentlemen, I now call on Mr. Arnold to conclude his paper by giving us his extemporaneous speech.

MR. ARNOLD:—First, before getting into my next subject, I want to voice my appreciation of the kind expressions that have been shown toward me here to-day both in words and actions, for this work on the New York Central, and I sincerely thank you. After all, there is no higher ambition that I know of for any man in this world, than to be able to accomplish something as he goes along through it, and write a record of that work, where those who follow him may read it, and perhaps be benefited by it; for, although we do the best we can, the probability is that those who examine our work one hundred years from now will wonder at the crudity of our methods, for with Tennyson,

> "I doubt not through the ages one increasing purpose runs,
> And the thoughts of men are widened with the process of the suns."

In regard to Mr. Potter's blacksmith; to the credit of Mr. Potter, he is a somewhat younger man than I am, and he probably does not remember that the original gauge of some of the railroads of this country was 6 feet. I have ridden over the Erie Railroad when it was what is known in railroad parlance as a "6-foot gauge." The man who established that gauge must have lived prior to Mr. Potter's blacksmith; and the only unfortunate thing for electrical engineers of the present day is that Mr. Potter and Mr. Sprague and Mr. Edison and Mr. Steinmetz and a few other distinguished gentlemen, who have been instrumental in developing the electric railway, could not have lived at the time Mr. Potter's blacksmith re-established the gauge for he might have been dissuaded from narrowing it. Now as to the extemporaneous speech. I want to say that it was my intention to deliver what I might have to say on this subject, extemporaneously if it came up at all; but about two hours before my train left Chicago, through the advice of my patent attorney, who knows my weaknesses, I concluded to write my remarks, so I hurriedly dictated them to my stenographer, grabbed my valise and took the train, leaving my speech to be written out, and it reached me as I came into the hall this morning. With your permission I will read it now.

Mr. Arnold then read his address entitled An Electro-Pneumatic Railway System."

PRESIDENT STEINMETZ:—I believe our INSTITUTE should be extremely grateful to Mr. Arnold, not only for contributing such a valuable paper as the one which he has just presented, but also for communicating to us his new ideas regarding alternating current railroading, and as Mr. Arnold communicates it at the close of his discussion, it shows that he does not desire a discussion thereon, which I fully agree with and appreciate, the more as he told us that his invention was approaching completion and actual results of operation would be forthcoming in a very short time. I hope and feel confident, considering the attachment Mr. Arnold has always shown for our INSTITUTE, that the results will be communicated for our discussion also. I will now call upon Mr. Mailloux to conclude the discussion on his paper.

MR. MAILLOUX:—Before passing on to my own paper, I would like to say a few words concerning the other papers; first in regard to Mr. Armstrong's paper. I have already commented in my own paper in terms of admiration on Mr. Armstrong's work, as shown in his Omaha paper. I do not want you to think I am unduly prejudiced in favor of Mr. Armstrong, but I wish to speak in terms of admiration for his present paper. To me it is one of the most interesting papers. It represents the analysis of facts by the analysis of principles; and to me it is the type of a paper which is not only useful for present purposes, but is also useful as a stimulating influence tending to develop the application of principles to other less known purposes. I therefore feel that the INSTITUTE is to be congratulated for a second classical effort on the part of Mr. Armstrong.

I have very little to say about the very excellent papers of Mr. Potter and Mr. Arnold; except to congratulate them both on the excellence of their work. These papers really require no discussion. I wish especially to congratulate Mr. Arnold on the fact that he became somewhat "demagnetized" himself on the alternating current motor question. At the time of the Buffalo meeting he was undoubtedly studying a "theory," and I can understand now, after having heard his "extemporaneous" speech, what that "theory" was; but, as his paper shows, in dealing with the actual case, he found himself, to use the words of a famous national duck hunter, "confronted with a *condition* and not a *theory*" and therefore had to deal with the case in a practical way, by resorting to direct current motors, which was the only practical thing to do.

Coming to my own paper, I wish to thank Mr. Dodd for the kind remarks which he has made and for the high implied compliment contained in them. I appreciate it all the more since Mr. Dodd himself is a mathematician of no mean analytical skill and knowledge, and since he is thoroughly familiar with the discussion of these problems. I wish to thank Mr. Dodd on this occasion for many valuable suggestions I have received from him personally in the pleasant relations we have had during the last five years. I may state that I am no longer entirely discouraged of being able to find an analytical solution of the problem he has referred to. The paper which I presented to-day offers some clues which may lead later to a perfect analytical solution. Not being able to solve the problem analytically, I did the next best thing, and solved it graphically. If we can find an equation, analytical or empirical, which can give us first the train resistance as a function of the speed, second the tractive effort in terms of either speed or current, then the solution would be easy. I have not yet found the analytical solution, but it is possible we may be able to find an empirical equation, and this may lead to an analytical solution of the problem, which, while not theoretically perfect, would be still of great practical value and convenience, and would therefore result in a still further simplification of the plotting of time-function curves.

MR. F. A. PATTISON:—Mr. President, the ladies of the Thursday Morning Club have been very kind to us during our stay, and I have been asked to bring before the Convention a matter which I can probably present more properly by making a motion. I move that the Chair appoint a committee of three, for the purpose of obtaining from the members of the INSTITUTE a subscription, for a loving cup to be presented to the Thursday Morning Club.

[The motion was carried unanimously and the session adjourned.]

At 10 o'clock on the morning of June 19th, Dr. Arthur E. Kennelly lectured before the Thursday Morning Club and its guests, at Kellogg Hall on the subject of " Wireless Telegraphy."

At 4 o'clock in the afternoon the INSTITUTE was entertained at an Organ Recital at " Barrington House," with the compliments of Mr. Searles.

At the links of the Wyantenuck Golf Club in the afternoon, there was an open air concert, and light refreshments were served.

In the evening by invitation of the Thursday Morning Club, there was an Assembly at the Town Hall, participated in by the residents of Great Barrington and vicinity, and the members and guests of the INSTITUTE.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 20th, 1902.

THE FUNCTION OF SHUNT AND SERIES RESISTANCE IN LIGHTNING ARRESTERS.

BY PERCY H. THOMAS.

INTRODUCTORY.

In a paper read before this INSTITUTE on February 14 of the present year, the writer treated the subject of static disturbances in high tension lines and discussed some types of protective apparatus—chiefly the choke coil, the static interrupter, and the multi-gap lightning arrester. The function of the choke coil or interrupter was described as the prevention of local concentration of potential in windings of transformers or generators, such as is caused by waves of static electricity; the function of the lightning arrester, to prevent an excessive rise of potential of the protected circuit above the earth. The lightning arrester has also a secondary function of great importance, namely. the suppression of the arc which tends to follow a simultaneous discharge to ground from two legs of a circuit. The object of the present paper is the description of a new method of enabling an arrester to suppress such an arc, which is, of course, backed by the power of the generating system. This principle not being directly involved in the question of the protection of apparatus from static strains, received but bare mention in the paper referred to above.

The type of arrester about to be described involves the use of series and shunt resistance in connection with a multi-gap arrester. This type is important, as it permits the use of a very low series resistance with the arrester, giving a comparatively free discharge path to earth. That is, the chief advantage of the arrester using series and shunt resistance over that using only series, is the fact that the former may be made operative with a much smaller series resistance than the latter.

Some years ago, Mr. Henry Noël Potter discovered, in some investigations on lightning arresters for Mr. Wurts, that a voltmeter connected in multiple to some Wurts non-arcing metal A. C. arresters, prevented the formation of a permanent arc in the gaps. In this experiment a highly inductive circuit was being used, such as had been found very severe on the non-arcing power of these arresters. Investigation then developed the fact that the shunt path formed by the voltmeter was the cause of the suppression of the arc. Mr. Potter later made practical application of his discovery in the large generator switches at the power-house of the Niagara Falls Power Company. In these switches several breaks in series are introduced, some of which are shunted by resistance.

At a later date, Mr. Charles F. Scott proposed the use of this principle for the improvement of lightning arresters. Trial proved, however, that a great deal more was involved in the application of the principle of a shunt resistance to lightning arresters than to the large switches at Niagara, and it was found necessary to investigate the subject from the beginning. This work, which was carried out by the writer, developed some very interesting laws or principles, which will be fully discussed. The final result has been the design of a new type of commercial arrester, which includes not only a shunt resistance, but a series resistance as well. This arrester, which is adapted to A. C. circuits only, is called the low equivalent A. C. arrester, on account of its low spark-gap equivalent.

Principle of Operation.

The complete lightning arrester embodying the shunting principles is shown in Fig. 1, and consists of a number of small air

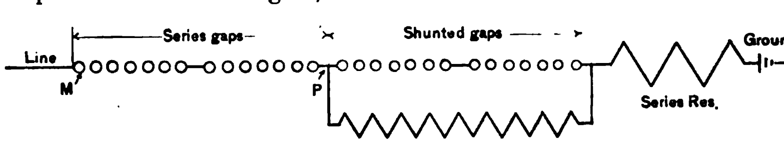


FIG. 1.—Low Equivalent A. C. Arrester, showing Series and Shunt Resistance.

gaps connected between line and ground, a portion of these gaps being shunted by resistance, marked "shunt resistance," and a series resistance placed in the earth connection. The shunt resistance is usually placed as shown, next the series resistance, and preferably half of the total number of gaps are shunted.

It is evident that when the arrester is not in action, the point P at the junction of the shunted and series gaps is at ground potential, and consequently that the arrester will discharge whenever the voltage of the point M of the line reaches a potential above the ground sufficient to cause the series gaps to break down; that is, the voltage on the line necessary to cause the arrester to discharge, is that required to break down the series gaps alone, regardless of the presence of the shunted gaps. This has a very important bearing on the protective power of the arrester.

During actual discharge, the operation of the arrester is as follows:

When the series gaps break down, the resistance between the points M and P is momentarily reduced to practically zero, and the full amount of the potential of the line is then thrown on the shunt and series resistances. If this potential, which is thus abruptly applied to the resistances, is high, the shunted gaps will be broken down. This makes, for the instant, a direct path for the static discharge from line to series resistance. Theory and experiment both show that practically no greater voltage, provided it be suddenly applied, is required to break down both series and shunted gaps than the series gap alone. This result is due to the fact that the two sets of gaps are broken down separately, one after the other. If conditions are right, current from the generator will then follow the static discharge through the gaps, establishing an arc. The current will flow through the shunt and series resistances and usually through the shunted gaps, but if the various parts are properly proportioned, the shunt resistance will take enough current from the shunted gaps so that the arc cannot hold in the latter, and will drop out. Once the arc drops out in the shunted gaps, it must pass through both resistances, which will reduce the current strength, and enable the series gaps to suppress it altogether.

The series resistance is found necessary for the successful operation of the arrester as outlined above, to prevent the enormous rush of current, which, on circuits of large generating capacity, would otherwise follow discharges and cause lights to dip, and synchronous apparatus to fall out of step, as well as over-heating the arresters themselves. This series resistance through which the discharge must pass, is evidently in general, an objectionable feature in the arrester, although it will be practically harmless if its amount is not too great. By the use of the shunt resistance, the value of the series resistance is kept comparatively small. This is the chief advantage of this type of arrester. A fuller description of the effect of the series resistance on the discharge of the line will be found in the paper to which reference has been made above.

Conditions Affecting Non-Arcing Power.

The capacity of an arrester to suppress or prevent the formation of an arc in its gaps after discharge, may be called its " non-arcing " power, and an arrester which is able to accomplish this result under all conditions for which it is designed, may be properly called " a non-arcing arrester." It is evident that an arrester will never be non-arcing when connected to a circuit whose normal electromotive force is high enough to cause the arrester to discharge. The non-arcing power of a combination of gaps and resistance under a given set of conditions will here be measured by stating the number of gaps required, under these conditions, to be just able to suppress the arc. The conditions determining the proper proportioning of parts in an arrester using shunt and series resistance may now be considered. Before taking up the subject of the shunting power of resistance, it will be necessary to outline the conditions covering the non-arcing power of a simple series of gaps with or without resistance in series, which is found actually to be the fundamental case.

Non-Arcing Power of an Unshunted Series of Air Gaps.

The use of a number of small air gaps in series in an arrester, rather than one large gap, is an essential feature in all arresters for high voltage circuits. The conditions affecting the non-arcing power of such a series of gaps are of two sorts. First, those involved in the physical and chemical construction of the gaps themselves, and second, those depending upon the constants of the circuit to which the gaps are connected. The conditions in the first class, being quite generally recognized, will be only briefly mentioned.

(1) *Non-Arcing Metal.*—There is a surprising difference in the non-arcing power of gaps of the same form but of different materials, even when tested under the same conditions. This very important fact was discovered by Mr. Wurts some years ago and has been fully described by him. Those metals which give

the greatest non-arcing power—commonly called non-arcing metals,—are zinc, bismuth, antimony, cadmium and mercury. The presence of zinc in an alloy will usually give this alloy a non-arcing quality. Copper, tin and iron are not suitable for lightning arrester work. The condition in which the terminal is left by a momentary arc, that is; whether it is pitted or whether it is beaded, so that the gap is partly bridged over by the melted material, varies markedly with different materials. This point is a very important consideration. Iron has a tendency to bridge the gap, while non-arcing alloy pits slightly, leaving the gap virtually in as good condition as before the occurrence of the arc. In choosing his non-arcing alloy, Mr. Wurts used such proportions of zinc and copper that the effect of the zinc, which pits, is just balanced by that of the copper, which beads.

(2) *Multi-Gap Principle.*—The fact that a series of gaps is a much more powerful non-arcing device than a single gap which requires the same voltage to start a discharge, is probably due partly to the chemical or electrolytic actions occurring at the surface of the terminals, and partly to the cooling effect of the metallic terminals, which, in the small gaps, are so close to the arc. When an arc is suppressed by the gaps of an arrester, the current drops out as it passes through its zero value, and the air rapidly regains its insulating quality, so that when the electromotive force is reversed, and the current tends to build up in the opposite direction, the arc is suppressed, since the gap has lost its conducting power. The remarkable speed with which incandescent air can become cool is shown by the fact that very rapidly moving objects viewed by the light of a static spark passing through air, appear stationary. This means that while the air has become incandescent and has cooled again, the moving body has not changed its position sensibly.

(3) *Length of Gap.*—With gaps between 1/64″ and 1/16″, the non-arcing power varies somewhat less than proportionally to the length of the individual gaps.

(4) *Minor Conditions.*—The temperature of the terminals of the gaps is quite an important condition, as a great increase of temperature reduces the non-arcing power of the gaps. The non-arcing power of the so called "non-arcing" alloy falls off materially after very long continued hard service. This is probably because the zinc is gradually burned out.

Those conditions affecting the non-arcing power of a series of gaps which depend on the constants of the circuit to which the gaps are connected, may be called the "circuit conditions." The "circuit" must include all apparatus actually connected to the system. Circuit conditions are, chiefly, the voltage of the generator, the capacity of the system to deliver current on short-circuit through the gaps, the equivalent inductance through which such current flows, the frequency of the system, and the phase of the generator e.m.f. at which the discharge starts.

The following laws have been experimentally determined with gaps of non-arcing alloy, each approximately 1/32", and do not necessarily apply to other conditions without modification.

(1) *Generator Voltage.*—With the total power and the power

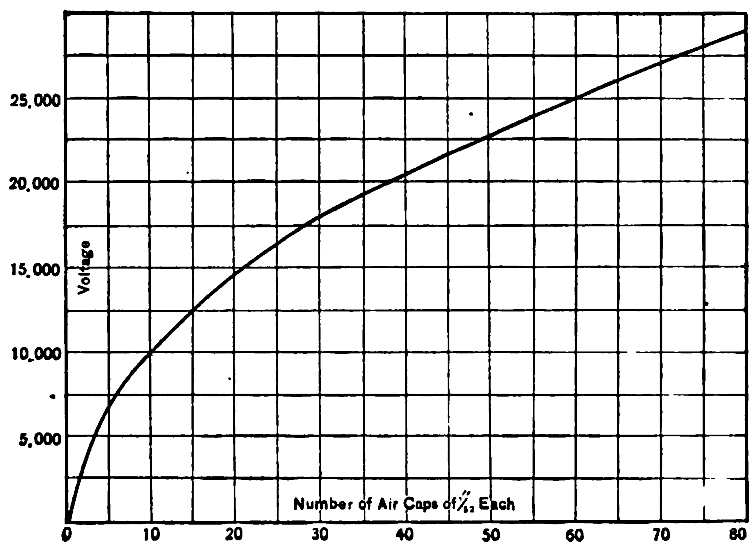


FIG. 2.—Number of Gaps necessary to withhold Normal Voltage with Sine E.M.F. Wave and no High Tension Lines Connected to Circuit.

factor of the circuit as a whole constant, the number of gaps necessary to suppress an arc is somewhere nearly proportional to the voltage of the generator. This number of gaps, however, does not increase quite as rapidly as the voltage. That is, if we place the gap across the terminals of a raising transformer supplied by a generator, and then connect the secondary coils of the transformer in various symmetrical combinations, so as to give different voltages (in all cases using the whole of the transformer winding), under these conditions the number of gaps required is approximately proportional to these transformer voltages. If, however, the strength of the current following a discharge, or the inductance of the circuit, is kept constant as the voltage varies, the number of gaps is by no means proportional to the voltage of the circuit.

It is interesting to note that the number of gaps required to withhold the generator voltage and prevent its breaking down the gaps without the aid of a static discharge, obeys an entirely different law from the number required to suppress the arc after a discharge. The number of gaps required to hold the given voltage under one particular set of conditions is shown in Fig. 2. This is to be compared with a straight line, which shows approximately for different voltages the gaps required to suppress an arc when once started.

(2) *Short-Circuit Current.*—The voltage, inductance, etc., remaining unchanged, the non-arcing power is proportional to a power of the short-circuit current between the first and the second, usually more nearly following the second. This law is not unexpected, assuming the cause of the holding of the arc in the gaps to be the heat generated, since the amount of this heat is proportional to the square of the current and to the resistance, the resistance, of course, decreasing with an increase of current. With large current and high power factor, the non-arcing power is more nearly proportional to the first power of the current, but with small current at low power factor, it follows the second power quite closely.

This law is a most important one as regards commercial lightning arresters, since the growth in the power of central stations means large currents flowing on short-circuit, which in return requires many gaps, and since the minimum practical gap is soon reached, an excessive equivalent gap between line and ground will result. As long as plants were only very moderate in capacity, the multi-gap arrester without resistance was perfectly adequate for all cases, but with the very large installations of the present time, this is no longer true, and with such systems some resistance should be used to increase the non-arcing power.

In determining the short-circuit current that will flow through the arrester after a static discharge, not only the capacity of the generator itself to deliver current on short-circuit must be considered, but also that of all synchronous apparatus, storage batteries and even induction motors, under some circumstances. With two generators in parallel, more gaps are required than with a single generator. If a resistance be placed in series with the air gaps, the amount of current flowing after a discharge will be reduced, and fewer gaps will be non-arcing. This resistance has much the same effect, so far as the gaps are concerned, as reducing the capacity of the generators.

(3) *Inductance.*—With a given current and a given voltage, non-arcing power varies inversely as the inductance in circuit. This law is only approximate. With large amounts of inductance, the non-arcing power does not fall as fast as the inductance increases.

This is a most important condition, for the inductance of a generating system varies inversely as its power, other things being kept in proportion, so that as far as this condition alone is concerned, the large generator produces an easier condition for the gaps than a small one, since the inductance is less. On the other hand, the large generator will give a larger short-circuit current, which affects non-arcing power more nearly as the square, consequently the total result of increasing the capacity on the system is to reduce the non-arcing power of a given series of gaps.

The effect of the inductance in the circuit may be considered as a function of the energy stored electro-magnetically. This energy is equal to $\frac{1}{2}$ I^2 L. When this stored energy is large, the wave form of the e.m.f. in the gaps is flattened so as to give a very short period for the small values of the current near the zero point of the wave. This, of course, reduces the opportunity for the cooling of the hot gases of the arc. In some cases, there may even be an increased voltage above the normal, due to the stored energy, although this rise will never be of serious moment, as even a small increase of normal potential will merely cause the gaps to continue to discharge. Experiment shows the effect of a given quantity of stored energy to be less effective in reducing non-arcing power on low voltage and large currents than on high voltages and small currents. This difference is quite marked.

The effect of inductance in the circuit is very noticeable to the eye and ear. When the inductance is large, the arc in the gap is much quieter, but more persistent and may continue as long as one second and then drop out. This delay in the suppression of the arc probably represents the period necessary to consume the energy stored in the magnetic field by the initial rush of current following the static discharge. This original discharge, having a very high current density, reduces the resistance in the gaps to practically zero, and for several alternations thereafter this resistance is probably increasing period by period.

It is very difficult to compare the non-arcing power of similar gaps on different voltages, for of two circuits having the same power factor, one running at double the voltage of the other, that having the higher voltage will have an inductance and resistance four times as great as the other. To have the same stored energy in both cases, the first circuit must have half the current of the second, but half the current means a different heating effect, so that the conditions of the two cases as regards current are not comparable. Of the two circuits of different voltages, that of the higher is more difficult to control, as far as its inductance is concerned, but on the other hand, if the total power of the generating apparatus be the same in the two cases, it will have a small current, which means less heat in the arc.

For a circuit of given voltage, it is readily seen that the addition of inductance to a non-inductive circuit containing a series of air gaps, such as is under discussion. has the effect, if the inductance be comparatively small. of increasing the severity of the conditions on the gaps, for although the current is slightly reduced, yet the stored energy as a whole is increased considerably on account of the great percentage of increase of the inductance, but as more inductance is added, the current is more and more rapidly decreased, so that, although the inductance still increases, a point is finally reached at which the stored energy, which depends on the square of the current, will be as a whole decreased by the addition of further inductance. When this point is reached, further increase of inductance renders the conditions on the gaps easier.

(4) *Frequency.*—The frequency, at least between 25 and 60 cycles, is not very important in its effect on non-arcing power. The length of a single alternation is, of course, longer with the lower frequency, so that more heat units are produced by a given current before the zero point of the current arrives, but the time of duration of the period of small current, also lasts longer with the lower alternations, giving a compensating effect. The stored energy, of course, does not depend on the frequency. Experiment shows that if anything the lower alternations are the more severe on the lightning arrester.

(5) *Phase of e.m.f. at time of Discharge.*—The phase of the electromotive force wave of the generator at the instant of static discharge is an extremely important condition, for when the dis-

charge occurs with the generator e.m.f. nearly zero, no arc will be formed in the gaps with any condition of inductance or capacity of generator. There is, therefore, a certain portion of each alternation in which a discharge will be unable to start an arc; just how large a proportion of the alternation this will be, depends upon the non-arcing power of the gaps. In a successful arrester this period must include the whole alternation. If discharges are passed at random without relation to the phase of the generator e.m.f. in making tests of non-arcing power, it will be found that 25 to 50 or even 100 trials must be made to be certain of producing the severest condition. For this reason, there will be a great variation in the apparent severity of the discharges of arresters of this type on actual lines, for lightning occurs at random, at different phases of the generator e.m.f., causing a greater or less tendency of the arc to follow; this will naturally cause a larger or smaller flash in the gaps

The chief conditions upon which the non-arcing power of a given series of air gaps depends have been considered, and the powers and limitations of the arrangement pretty well outlined. It is evident that for very large plants, the number of gaps necessary to secure satisfactory non-arcing power will render the protective power of the arrester inadequate. This difficulty may be overcome by the use of series and shunt resistance in the manner already described.

Shunt Resistance.

The effect of adding a resistance to shunt a portion of such a series of gaps as has just been discussed, will next be considered. If the addition of this shunt resistance is to better the conditions as regards suppressing the arc, then the proportion of parts must be such that without the shunt resistance the full number of gaps in the arrangement considered will fail to be non-arcing. In what follows, it will be assumed that the static discharge occurs at the phase most favorable for the continuance of the arc in the gaps. It will be readily seen that after the passage of the static spark, the current which will flow through the shunted gaps, will, on account of their resistance, produce a certain amount of voltage across the shunt resistance, which must, therefore, take a certain amount of current. This current will evidently be subtracted from the current in the shunt gaps. The decrease in the latter current increases the resistance in the shunted gaps, which throws more current into the shunt resistance, and so on. If, now, the current in the shunted gaps is only just sufficient to maintain an arc when no shunt resistance is present, then the subtraction of a portion of this current will cause the arc to drop out in the shunted gaps. This forces all the generator current to flow through the shunt resistance. All current, of course, flows through the series gaps, and the series resistance. With the arc suppressed in the shunted gaps, the shunt resistance will then reduce the strength of the current in the series gaps, and, if it be great enough, will render them non-arcing. The laws determining when the shunt resistance will be able to withdraw sufficient current to cause the arc to drop out in the shunted gaps, have been determined as follows, the shunting power being measured by the greatest number of ohms per shunted gap allowable in the shunt resistance.

(1) *Number of Shunted Gaps.*—The amount of resistance which will allow the shunted gaps to be non-arcing is proportional to the number of these gaps.

(2) *Short-Circuit Current.*—The number of ohms allowable per shunted gap is proportional approximately to the square of the current which flows through the shunted gaps immediately following the static discharge. The "ohms per gap admissible" do not fall, however, quite as fast as the square of the current increases, so that doubling the current does not reduce the ohms per gap to quite one-quarter of its previous value.

(3) *Power Factor.*—The ohms per gap depend to a slight extent upon the power factor of the current following the discharge through the shunted gaps, being greater with low power factors. This is a fortunate circumstance, as circuits with low power factors are the most severe on arresters, and the ability to use a large shunt resistance allows the current and stored energy to be very materially cut down as soon as the arc drops out in the shunted gaps, which renders the series gaps more easily non-arcing.

(4) *Ratio of Series to Shunted Gaps.*—One very unexpected result is discovered, viz.: that the ohms per shunted gap depend largely on the ratio between the number of the series and shunted gaps. If the series gaps greatly exceed the shunted in number, the shunting power of the shunt resistance is much reduced, and vice versa, if the shunted gaps exceed the series gaps, the shunting power is increased. The objection to using more shunted gaps than series gaps is that a reduction in the protective power in the arrester will result, since more voltage will be required to

break down the shunted gaps and discharge the line, than is required to break down the series gaps.

(5) *Frequency.*—The frequency has little effect in the shunting power between 25 and 60 cycles; if anything the lower alternations are the more severe. It is fortunate that non-arcing power is nearly independent of frequency, as standard arresters may be designed for use upon circuits independent of frequency.

Method of Design of Arrester.

With the above outline of the laws governing the shunting power of resistance, it is now possible to outline a method of designing an arrester which will be perfectly non-arcing under any conditions assumed. First, determine the current given on short-circuit by the system. In doing this, the following factors must be considered.

(*a*) *Generator Field Reaction.*—As this is roughly proportional to the current, its effect will be the same as a resistance in series with the circuit, and its equivalent ohms may be determined from the characteristics of the generator.

(*b*) *Inductance and Resistance.*—The true inductance of the armature which must be separated from the field reaction, the effect of all synchronous apparatus, which for the moment will act as a generator, the resistance and inductance of the line, transformers and auxiliary apparatus must be determined. When all these characteristics are together considered, the approximate short-circuit current and the stored energy may be approximated.

A number of gaps which is able to withhold the maximum normal line voltage with a suitable margin, must then be chosen. If this number of gaps, unaided by resistance, is able to suppress the short-circuit current with the given amount of stored energy, the arrester may be considered complete. If such a series of gaps is not non-arching with the given conditions, the number of gaps should be doubled and one-half of them shunted by resistance and a series resistance added. The total amount of resistance must be such as so to cut down the short-circuit current,that the series gaps will be non-arcing with the actual stored energy of the system. The largest possible portion of this resistance should be shunted, consistent with the ohms per shunted gap being sufficiently low to have the shunt effective. The remaining part of the resistance will constitute the series resistance. It may thus be seen that the use of series and shunt resistance may be made to give the freest practicable discharge path for a given set of conditions, with the multi-gap type of arrester, and at the same time be non-arcing under all the given conditions.

METHOD OF INVESTIGATION.

A brief description will be given of the method of making the experiments from which the laws stated in this paper were determined. Tests have been made on a number of different generators, and at a number of different voltages. In each case, the diagram of circuits was in effect like Fig. 3, except that in some cases raising transformers were omitted.

A is the generator supplying current to the gaps; R the raising transformer sometimes used to obtain the required voltage on the gaps. At D are the gaps to be tested; C and R are either

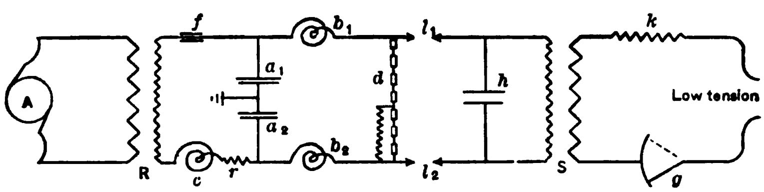


FIG. 3.—Diagram of Connections for Tests on Non-arcing Power.
a_1 b_1 a_2 b_2 = Static Interrupter.
A and R = Power Circuit.
r and c = Adjustable Resistance and Inductance.
d = Gaps being tested.
f = Fuse to Open Arcs.
l_1 l_2 h = Gaps and Condenser to Produce Static Sparks.
S = Raising Transformer for Static.
g = Swinging Switch.

inductance or resistance or both, placed in the main circuit to control the short-circuit current or the stored energy. B_1 B_2 are small choke coils in main circuit. A_1 and A_2 condensers to ground. A_1, B_1 and A_2, B_2, form two single-pole static interrupters to protect the raising transformer from the static strains produced in sending sparks over the gaps. F is a fuse used to open the main circuit when the gaps fail to interrupt the arc. This fuse, which usually consisted of one or more strands of No. 23 German silver wire, in a long tube, was found to open the circuit easily under the worst conditions tried.

To obtain the exciting static spark, a high tension transformer was used at S, with a ratio suitable for breaking down two gaps, L_1 and L_2, which were so adjusted that the discharge of the condenser H, resulting from their breakdown, was sufficient to force a discharge across the gaps at D. A resistance was used in series with the low tension winding of this transformer to prevent any current flowing from s through the gaps, etc., other than the charge of the condenser. The circuit of this transformer is closed on the low tension side, whenever a spark is desired, by a swing switch with a long arm making momentary contact at G. The apparatus was so adjusted that for each swing of the switch a clear, single, purely static spark crossed the gaps at D.

In making the tests, a great many combinations of inductance and resistance were used, and in each combination several numbers of gaps, and with each number of gaps from twenty-five to fifty sparks were passed, so that the phase of the wave most favorable for the arc's holding was practically certain to be tried.

This sort of testing is very laborious, very slow and involves considerable risk to apparatus, and the results when obtained will always vary quite widely, even under apparently the same conditions—as would be expected from the nature of the phenomena. Therefore, it must not be expected that the relations that have been described will hold with anything like the accuracy of many electrical relations. They should be considered rather, general laws from which individual tests will vary in one direction or the other, more or less, on account of ever changing secondary conditions.

In the use of series resistance in lightning arresters, there is a great temptation to limit the short-circuit current to an unsafe degree, as this reduces very much the difficulty of constructing a non-arcing arrester. Prevention of an arc is in itself a comparatively easy matter, but to secure good protection at the same time, the short circuit and the arc through the gaps cannot be strictly prevented but must be allowed to occur and then be suppressed. This is the difficult problem. The use of shunt and series resistance furnishes a means of reducing very materially the obstacle offered by series resistance to perfectly free discharge. Any further steps in the same direction should be welcomed.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 20th, 1902.

THE ELECTROSTATIC WATTMETER IN COMMERCIAL MEASUREMENTS.

BY MILES WALKER.

That a quadrant electrometer may be used as a wattmeter for measuring power has been known for many years. In the *Transactions of the Royal Society* (1891), Vol. 182, p. 519, will be found a discussion upon the subject by Ayrton, Perry and Sumpner, in which the precautions to be adopted in order to make a successful instrument are considered.[1] In 1898 Prof. Ernest Wilson[2] published the results of some experiments which showed the accuracy of the instrument at all power factors. Mr. Addenbroke in a paper before the International Electrical Congress at Paris in 1900[3] showed how the instrument could be arranged for universal electrical measurements. Nevertheless, the electrostatic wattmeter is almost unknown to electrical engineers, and certainly its advantages over other types of wattmeter are not fully appreciated. These advantages may be enumerated as follows:

(1) It can be made to give very accurate readings at low power factors.

(2) It is particularly well adapted for high voltage work, because it does not require a high non-inductive resistance.

(3) It is cheap and simple in construction.

(4) When constructed for low voltage work, it will not be so likely to be burned out by accident as an ordinary wattmeter.

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1. See also Prof. J. A. Fleming's "Alternate Current Transformer," Vol. II, p. 551.
2. *Proc. Roy. Soc.* (1898,) Vol. 62, p. 356; also *Elec. Review*, London, March 4, 1898.
3. *Electrician* (London,) Oct. 5, 1900; also *Elec. Eng.* (London,) Feb. 2, 1900.

(5) By the use of suitable adjuncts the same instrument may be used to measure any power from 1 watt to 5,000 kilowatts.

(6) Its operation is based upon simple laws, so that when its needle is controlled by gravity, it can be relied upon as a standard instrument.

The disadvantages connected with its use are:

(1) It is not portable.

(2) The controlling forces are in general small, so that the instrument though dead-beat, is slow in reading.

(3) Its general behavior must be understood by the operator.

I propose in the present paper to discuss the principles that underlie the design of the electrostatic wattmeter for commercial work, and some of the uses to which the instrument may with advantage be applied. I am indebted to the Westinghouse Electric & Manufacturing Company for having had the opportunity of experimenting on this instrument, and to Mr. Percy H. Thomas, whose ideas and suggestions have been invaluable. It is one of the characteristics of American firms which have helped them to attain their present high position in the manufacturing world, that they are not afraid to spend a little money on theoretical investigation wherever there is a fair chance of some point being gained.

In designing an instrument for any class of work, it is desirable to know approximately the forces upon the moving part. The method of calculating the forces on the needle of a quadrant electrometer, as given in the standard text-books, does not appeal to the ordinary engineer, because the result is not expressed in the units with which he customarily deals. The following simple method is perhaps more acceptable:

Consider a U-shaped piece of metal C, Fig. 1, embracing a sheet of metal B. Let the size of the plates be great compared with the distance s between them. Let B be constrained so that it can only move in its own plane along the line O X. Let the length B in the direction at right angles to O X be l. Let V = number of volts of potential difference between B and C. Then V/300 is the number of electrostatic units of potential difference.

If A is the effective area on the upper side of B, 2A is the total effective area.

The total charge Q on the plate B will be

$Q = (2A/4\pi s) \times (V/300)$ electrostatic units of quantity.

The total store of energy in the electrostatic field will be

$$W = \frac{1}{2}\,\frac{V}{300}\,Q = \frac{A}{4\pi s} \times \frac{V^2}{90{,}000} \text{ ergs.}$$

Suppose, now, that the plates are connected to a generator so that the voltage between them remains constant no matter how they are moved, and the plate B is moved through a short distance dx so as to alter A by a little bit d A. The little change in the store of energy will be

$$d\,W = (d\,A/4\,\pi\,s) \times (V^2/90{,}000)$$

From Fig. 1, $d\,A = l\,d\,x$, and since the mechanical work done in moving the plate must equal the electrical work dW, we must have $d\,W = F\,d\,x$, where F is the force upon the plate. Therefore

$$F = (1/4\,\pi\,s) \times (V^2/90{,}000) \text{ dynes.}$$

If the plate B instead of moving parallel to itself moves about a center as at Fig. 2, we have $d\,A = r^2\,d\,\theta$, and $d\,W = T\,d\,\theta$, so that the torque

$$T = (r^2/4\,\pi\,s) \times (V^2/90{,}000)$$

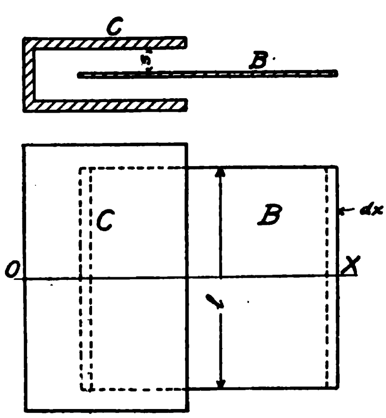

FIG. 1

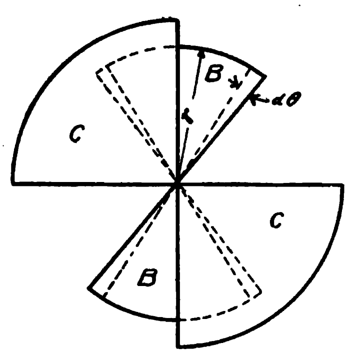

FIG. 2

where T is in dynes at a centimetre, r and s are in centimetres and V in volts.

$$\text{Let } (r^2/4\,\pi\,s \times 90{,}000) = k.$$

Take now the quadrant electrometer Fig. 3 and let the pressure between the needle and one set of quadrants be V volts and the pressure between the needle and the other set be $V + a$. Then, as one set is pulling one way and the other set the other, the torque is proportional to the difference between the squares of the voltages, or

$$T = k\,[(V + a)^2 - V^2] = k\,(2\,a\,V + a^2).$$

If we connect a quadrant electrometer to an electric circuit in the manner shown in Fig. 4, in which the current to the motor is passed through a non-inductive resistance of R ohms, causing a drop of a volts, the torque on the needle at any instant will be

$$T = k\,(2a\,V + a^2) \qquad (1)$$

If, now, V is large compared with a, we have approximately

$$T = 2k\,a\,V = 2\,R\,k \times V\,c$$

The power supplied to the motor is $V\,c$ and if the needle is suspended so that its deflection is proportional to the torque, the deflection will be approximately proportional to the power supplied to the motor.

In the case of the alternating current we must take for V and a the expressions $\sqrt{2}\,V \sin 2\,\pi\,n\,t$ and $\sqrt{2}\,a \sin(2\,\pi\,n\,t + e)$, respectively, where e is the angle of lag. Substituting these values in equation (1), integrating throughout one complete

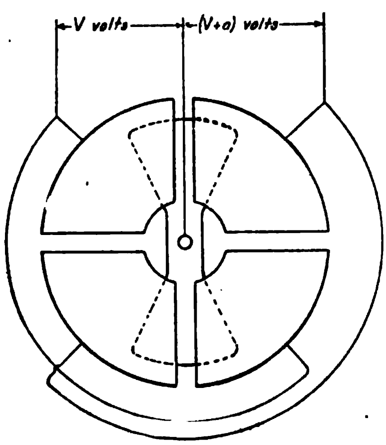

FIG. 3

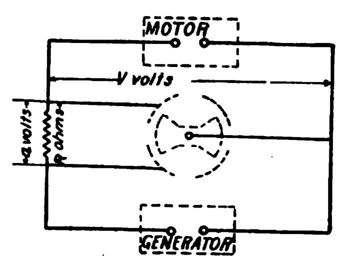

FIG. 4

cycle and dividing by $2\,\pi$, we get the mean value of the torque throughout the cycle.

$$T = 2\,V\,a \cos e + a^2 = 2\,R\,k\,\left(V\,c \cos e + \frac{c^2 R}{2}\right)$$

The electrostatic wattmeter reads the power correctly whatever be the shape of the wave form, for at any instant the turning moment is proportional to the instantaneous value of the power and the needle takes up a position that corresponds with the average of the instantaneous turning moments.

It will be seen that the term a^2 is independent of the power factor $\cos e$, so that, when e is great, a considerable error may be produced in the measurement of the power, unless we take some precautions either to correct for this term or eliminate it altogether. Several methods are employed by the Westinghouse Electric Manufacturing Company for eliminating the term a^2 when working with low power factors. The best method to adopt in any particular case depends upon the kind of measurement that is being made. When working with high voltages, in measurements upon insulation losses, it is convenient to use only a fraction of the total voltage for the term V. The reason for this is that if we put 30,000 or 40,000 volts between the needle and quadrants we would be troubled with brush discharges, unless a very large instrument with large rounded conductors were employed. It is more convenient to take a tap off the transformer supplying the power, and make the connections as in Fig. 5. If the ratio between the total voltage of the transformer and the voltage upon the needle be n, we may eliminate the a^2 term by putting in series with the transformer, at the terminal opposite the one to which the quadrants are attached, another non-inductive resistance, such that the drop in that resistance is equal to $a\ (n/2 - 1)$.

Suppose, for instance, that $n = 4$ and that to get a good reading we have a resistance of 0.1 ohm between the quadrants. If we put a resistance of $0.1 \times (4/2 - 1) = 0.1$ at the opposite terminal of the transformer the instrument will read correctly whatever may be the values of V, a or e. The proof of this is as follows:

The voltage between the needle and one set of quadrants is $(V/n + a/2)$ and between the needle and the other set of quadrants it is $(V/n - a/2)$

$$T = k\left[\left(\frac{V}{n} + \frac{a}{2}\right)^2 - \left(\frac{V}{n} - \frac{a}{2}\right)^2\right] = \frac{2\,k\,V\,a}{n}$$

The simple application of this rule occurs when $n = 2$. In this case $(n/2 - 1) = 0$, so that no additional resistance is required. In making measurements at pressures of 10,000 volts, it is convenient to connect the needle to the middle point of the transformer supplying power, and then the a^2 term is eliminated.

In other cases where it may be inconvenient to insert the additional resistance, an ampere-meter may be inserted, from the reading of which a may be calculated and the readings corrected. The term a is equal to $c\,R$. The calibration of the instrument and correction of the readings may be carried out very simply in the following manner: One pair of quadrants is connected to the needle and a continuous voltage V_1 (say 100 volts) is applied between the needle and the other set of quadrants. From the deflection D_1 produced we get the constant of the instrument from the formula

$$K D_1 = V^2_1$$

In any measurement of power if our arrangements are such that the a^2 term does not appear, then for any deflection D we calculate the power from the equation

$$\text{Watts} = (n K D / 2 R)$$

But, if we cannot neglect the a^2 term we use the formula

$$\text{Watts} = \frac{n K D}{2 K} + \left(\frac{n}{2} - 1\right) C^2 R$$

The instrument connected up as in Fig. 5 (preferably with $n = 2$) is suitable for making measurements on dielectric losses in insulating material. In these tests there is no objection to

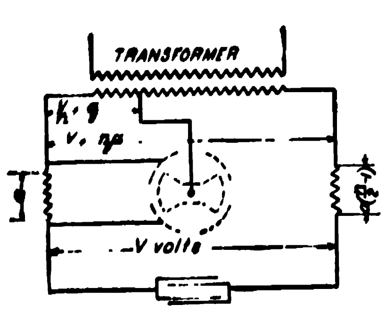

FIG. 5

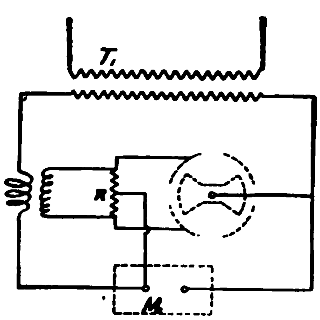

FIG. 6

making R very large so that good deflections may be obtained even when the current is exceedingly small. For instance, the power supplied to a few square inches of paper subjected to a pressure of 20,000 volts between metal plates may be measured with considerable accuracy.

The accuracy of this instrument with low power factors, its wide range and freedom from burning out, make it suitable for general testing purposes, whenever low power factors are likely to be met with. It is well-known that when the power of a 3 phase motor is measured in the ordinary way, with two successive readings on a wattmeter, one of these readings will be negative, or of very low power factor, when the motor is lightly loaded. We may have to take the difference between two readings, both of which are inaccurate on account of the effect of the low power factor upon an ordinary wattmeter, and the final results will be very far indeed from accurate. An electrostatic wattmeter may be made to read power supplied at pressures as low as 100 volts, but in order to get good forces upon the needle it is desirable to increase the voltage a between quadrants. This necessitates the elimination of the a^2 term in equation (1). The best method of doing this for low voltage commercial work is that shown in Fig. 6.

T_1 is the transformer supplying the power to be measured.

M_1 is the apparatus absorbing power.

T_2 is a series transformer of suitable ratio, whose secondary is connected in series with a non-inductive resistance R. One pair of quadrants is attached to one end of this resistance and the other pair to the other end, the needle being connected to the opposite side of the system. The middle point of the resistance R (or if preferred, the middle point of the secondary of the transformer) is connected to the same terminal of the apparatus absorbing power as the primary of the series transformer. If a is the voltage across the resistance R, it is easy to see that the torque

$$T = k\left[\left(V + \frac{a}{2}\right)^2 - \left(V - \frac{a}{2}\right)^2\right] = 2\,k\,V\,a$$

The series transformer may be made so that the error due to its use is not more than one part of one thousand on high power factors, and one part in one hundred on low power factors.

A simpler method, though not quite so satisfactory, is that shown in Fig. 7. Here an auto-transformer T_3 has its middle point and one terminal connected to the resistance R,and the two outer terminals are connected to the quadrants. The middle point of the transformer being connected directly to the apparatus M in which the power is absorbed, the a^2 term is completely eliminated.

For polyphase work, it is convenient to use an instrument with two needles on the same shaft, just as in an ordinary polyphase wattmeter. The connections for a 3-phase instrument are shown in Fig. 8.

For a standard instrument, in which the deflecting forces are not too small, a bifilar suspension is the most satisfactory means of controlling the needle. Several precautions, however, must be taken to make a bifilar suspension satisfactory. The well-known formula for this suspension tells us that for small deflections the turning moment in grams at a centimetric =

$$\tfrac{1}{4}(1 - m^2)\,(P\,y\,z/L)\sin\theta$$

where m is the ratio between the difference and the sum of the tensions in the fibres. P is the total weight of the needle in grams, y the distance between the fibres at the top, z the distance between the fibres at the bottom, L the length of the fibres and θ the angle turned through. All the distances are in centimetres. From this it is seen that it is very necessary to keep the tensions in the two fibres constant. A very good method of doing this is to hang the block to which the fibres are attached to short strips of phosphor-bronze at a considerable distance apart in the manner shown in Fig. 9. A line joining the strips

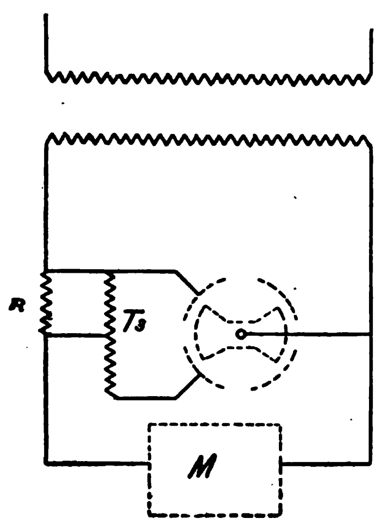

FIG. 7

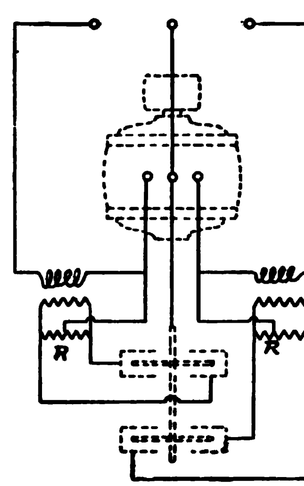

FIG. 8

is at right angles to the line joining the fibres, so that the block is free to tilt and equalize the tension in the fibres. By the addition of small weights screwed into two projecting arms, the ratio between the tensions may be adjusted to any degree of precision, and when once adjusted is independent of changes in the leveling of the instrument.

It is desirable to have the distance between the fibres as great as possible, so that microscopic changes in this distance from accidental causes will not change the constant of the instrument. From $\frac{1}{8}''$ to $\frac{1}{4}''$ makes a good working distance, if care is taken to make the point of suspension of each fibre perfectly definite.

Fine phosphor-bronze strips make strong and satisfactory suspending fibres. The spindle of the needle should be fairly heavy so that the tension of the fibres is not altered perceptibly by small unbalanced electrostatic attractions. By putting weight in the spindle, the moment of inertia of the needle is very little increased. The needle should be made as rigid as possible and with a very small amount of inertia. For high voltage work, the forces upon the needle are so great that a single needle is sufficient. For low voltage work it is best to use a number of

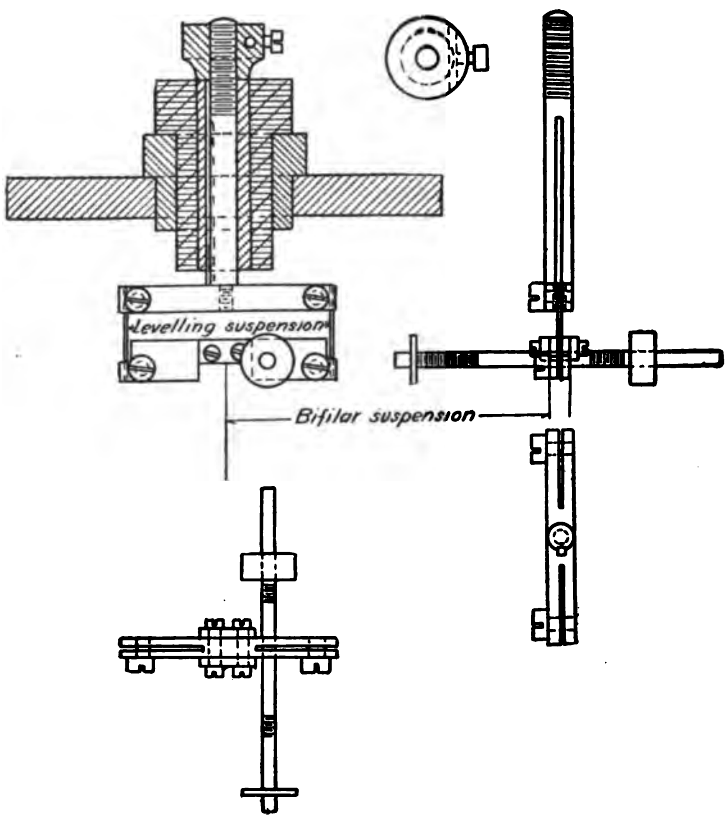

FIG. 9

small needles in a multicellular instrument. The moment of inertia of the needle, even if its thickness remains constant, goes up as the fourth power of its linear dimensions; whereas, the turning moment only goes up as the second power. A number of small needles may, therefore, be made more rigid and with smaller moment of inertia for the same turning moment than one big needle.

The needle and all attachments must be so shaped and guarded as to have no forces upon them except those due to the quadrants. For this reason it is well to avoid making projections on the frame or stationary parts of the instrument that can attract or repel any part of the needle. All visible parts of the needle and its spindle should as far as possible be figures of revolution, so that even if there is an unsymmetrical field outside the quadrants, it cannot produce a turning moment. The mirror should be placed in a cylindrical metal screen, kept at the same potential as the needle.

The distance between the needle and the quadrants is a matter that requires some consideration. In high voltage work the distance must, of course, be great enough to prevent accidental sparking over. Any unbalanced forces on the needle due to want of symmetry are decreased by increasing the distance from needle to quadrants. As there is no great difficulty in getting sufficient turning moment with high voltages, it is well to allow ample distance. An instrument intended to work up to 10,000 volts should have an inch as the shortest distance between needle and quadrants. The greatest difficulty met with in very high voltage work is the brush discharge that occurs from the needle. This sets up electric winds which react upon the needle and make it wander. The liability to brush discharge depends upon the steepness of the gradient of electric potential in the air space surrounding the needle, and may be very much diminished by rounding off all edges. The electric winds set in at a voltage far below that required to produce visible brush discharge. In fact, a needle intended for a pressure of 10,000 volts should have its edges rounded off to a radius of not less than one-eighth of an inch, and should be nicely polished and free from dust in order to work well. I believe that much of the trouble that has arisen in electrostatic instruments for high voltage work is due to incipient brush discharge rising from badly designed surfaces.

In a low voltage instrument the, distance s between quadrants and needle is settled by very different considerations. Even when there is very little chance of sparking, this distance should not be reduced below a certain limit. If the constant of the instrument is to be very accurately maintained, about $\frac{1}{4}''$ should be the lowest limit. Any shifting of the needle up or down from its central position changes the constant. When the needle is exactly central, the rate of change of the constant is 0. For small departures from the middle position, the rate of change of the constant is proportional to $4\,g/s^3$, where g is the little distance from the center. The smaller s is made, the more important become small movements of the needle in a vertical direction, due to expansion of the fibre or other accidental causes. However, if s be at least $\frac{1}{4}''$, a movement of the needle of 1/200 inch from the middle position causes an error of less than 0.05 per cent. A departure of 1/100 inch from the middle position, which should never occur in a well-made instrument, would cause a change in the constant of 0.2%. Another source of error arises from having the distance s too small in instruments controlled by a bifilar suspension. The attraction between the needle and the quadrants adds to or subtracts from the tension of the fibres, according as the needle is below or above the middle position. Where a fair distance between needles and quadrants is allowed, and sufficient weight put into the spindle, the error due to this cause is entirely negligible. The needle may be damped either by a copper cup swinging in a magnetic field or by a liquid damper.

The accuracy of an instrument depends greatly upon the closeness with which it preserves its zero. It is much more important to make an instrument which preserves its zero at all times than to make one which will give large deflections for small turning moments. A deflection may always be magnified or carefully read, but a wandering zero is a continual source of error. For this reason, a bifilar suspension with a considerable distance between fibres is the most satisfactory for a standard instrument.

We have used very successfully a suspension consisting of a single phosphor-bronze strip 0.001″ thick and 0.02″ wide. This shows very little " creep " and any error due to change of zero may be eliminated by taking the mean of readings on opposite sides of the zero.

When the accuracy of the readings is not so important, ordinary phosphor-bronze springs may be used to control the needle. For high voltage transmission lines, the electrostatic wattmeter has an advantage over other types for switchboard use, in not requiring a high voltage transformer. A good commercial instrument may be made for this purpose with a spring control.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 20th, 1902

ENERGY LOSS IN COMMERCIAL INSULATING MATERIALS WHEN SUBJECTED TO HIGH POTENTIAL STRESS.

BY CHARLES EDWARD SKINNER.

Those who have had occasion to test the dielectric strength of insulating materials by means of alternating e.m.f. are familiar with the fact that heat is always developed in these materials during such test. This is especially noticeable when the test is long continued at a point approximating the breaking down strength of the material. When the amount of material involved is large, ordinary indicating instruments will show at once that there is an actual loss of energy. The fact that energy loss exists under such conditions has been known for more than a decade, having been first shown by the experiments of Siemens, and later investigated by others. Published investigations on this subject relate almost entirely to the energy loss in the insulating material, or dielectric of condensers. The law of variation of loss, due to variation of voltage, was first announced by Mr. C. P. Steinmetz[1] early in 1892. At that time Mr. Steinmetz gave this loss the name of " dielectric hysteresis " because of its apparent similarity to the phenomenon known as hysteresis in iron and steel. Since that time other writers, notably Arno[2], Hess[3] and Borel[4], have made experiments from which they conclude that this energy loss is not in the nature of a dielectric hysteresis, and various theories have been advanced concerning its nature and cause.[5]

1. *Electrical Engineer*, March 16, 1892.
2. *Electrician* (London), March 3, 1893, and June 23, 1893.
3. *Journal de Physique*, April, 1893.
4. *Comptes Rendus*, May 23, 1893.
5. *The Electrician* (London), November 1, 1895.

It is not the object of this paper to discuss the theories of the origin or cause, but rather the effects of this loss, and in the absence of a name which can be accepted as descriptive and final, it will be spoken of as " energy loss " or " loss."

It is the intention to describe some of the methods employed and to give some of the characteristic results obtained from tests made on various materials used in commercial manufacture, and also on the insulation of finished apparatus. These tests have been made from time to time during the last five or six years, and have covered a great variety of materials. The major part of the tests, however, have been made on materials of a fibrous nature, such as paper and cloth, both in the treated and untreated state, and the discussion will be largely confined to this class. By treated material is meant a paper or cloth coated with some sort of insulating varnish. The samples used were taken from stock, and standard manufacturing methods were followed as far as possible in preparing them for the tests.

The action of ordinary commercial insulating material under high potential stress is usually so erratic, owing to surrounding influences, such as temperature, moisture, ventilation, etc., that a considerable number of observations are usually necessary in order to reach any satisfactory conclusions. For this reason the specific tests which are given in this paper are intended to show characteristic and not quantitative results, and are, therefore, not to be taken for other materials or even for other samples of the same material. Individual tests are of little value except as they fit in a series, or, unless the conditions surrounding them are known to the minutest detail.

For these tests, alternating current at the standard frequencies of 25, 60 and 133 cycles was used, the e.m.f. varying from a few thousand volts to upward of 100,000 volts. The majority of the tests referred to were made on material subjected to a potential stress much in excess of that ordinarily used in actual practice, this being done both on account of the fact that the various phenomena are much more marked at the higher stresses, and also because a much smaller amount of material could be used for each individual test. The results, while being true for potential stresses, are of little commercial importance in ordinary low potential apparatus. They become, however, of the greatest importance in very high potential working, and especially so with condensers for use on high potential circuits. The results also have a direct bearing on the question of long-continued tests of the dielectric strength of finished apparatus at very high voltages. The various phenomena noted are so inter-dependent that it is difficult to describe one without referring to others, and at times it will be necessary to anticipate results which are to be described later.

Variation of Temperature due to Variation of Stress.

When an alternating high potential stress is applied to insulating material, the temperature of the whole mass rises, but owing to the fact that all insulating materials are poor conductors of heat, the temperature of the inner portions rises above that of the outer portions, which have a better opportunity of dissipating their heat. A considerable number of tests have been made to determine the rise of temperature in the interior of a mass of insulating material under different conditions of stress. Usually these tests did not include the measurement of the amount of energy loss, as the results sought were the ventilation required under working conditions and the dielectric strength at various temperatures. The tests were usually made by placing the material between metal plates, which were connected to the terminals of a high potential transformer. The plates employed for this purpose should always have well-rounded edges to prevent the undue stress which occurs at sharp corners. The size of the plates varied in different tests, but the most satisfactory results were obtained with plates approximately 9″ in diameter, whose edges were rounded to a radius of about 1½″.

Various methods of measuring the temperature were tried, but only one gave entire satisfaction. A mercury thermometer inserted in the material gave trouble, especially at the higher potentials, as the mercury was vaporized by the static discharges in the thermometer tube. A small coil of very fine copper wire was placed in the material and the temperature determined by its increase of resistance. In long-continued tests this method was found unsatisfactory, on account of the rapid oxidation of the copper in the presence of the ozone always generated by such tests. The most satisfactory temperature readings were obtained by placing at the point where the temperature was to be measured, a copper-lead thermo-junction connected to a sensitive galvanometer. The outer ends of the couple were kept at 0° C. by being placed in ice water. By properly insulating the galvanometer, it was found entirely feasible to take readings with a potential stress of 30,000 volts or more across a ½″ layer of material, with this junction at the center. In some tests a number of junctions were placed at different points in the material, in order to map out the temperature of the various parts.

In a number of tests the material was arranged as above and then placed in a box in which was located an electric heater, a fan motor being used to circulate the air over the heater and through the box, so that any desired initial temperature could be secured and with care the surrounding temperature regulated throughout the test. In some instances insulation resistance was measured at intervals, the high potential wires being temporarily disconnected for this purpose. Usually the insulation resistance was so high as to be very difficult of exact measurement with the apparatus at hand.

The test samples used were built up to a thickness of $\frac{1}{8}''$ to $\frac{1}{4}''$ or more, and tests were made at different voltages up to the ultimate dielectric strength of the material. For most of the tests, current was obtained from a dynamo giving very approximately a sine wave of e.m.f. The results of this series of tests may be given as follows:

(1) With moderate stress the temperature of the material rises rapidly at first, then more slowly, then becomes constant. The actual rise in the temperature for a given voltage depends on the facility with which the material can dissipate its heat and on the temperature of the surrounding medium.

(2) As the stress is increased, a point is finally reached where the heat is developed at a greater rate than it can be carried away, and temperature then rises until the material chars and break-down results.

(3) When material is not thoroughly dried, the temperature rises much more rapidly than in well-dried stock. The increased temperature cannot be accounted for by the increased $I^2 R$ loss due to lower insulation resistance. The heat generated tends to dry out the material and the temperature may fall as the drying proceeds.

(4) With a considerable area of material under test, the temperature of small portions frequently rises above that of the surrounding material to such an extent that on examination these portions are found much discolored, while the surrounding portions remain unchanged. This effect is especially noticeable with treated material not perfectly cured. The final breakdown in such cases is invariably found in one of the heated areas.

(5) The final break-down in fibrous materials usually results from the burning of the material and not from mechanical rupture. When the e.m.f. applied is far above the dielectric strength of the material, the break-down may be due to a mechanical rupture. If, however, the e.m.f. is sufficiently low, so that an appreciable time elapses before break-down occurs, the break-down is probably due to burning caused by the heat generated in the material. There may be some attendant chemical action, but this is thought to be a result and not a cause of the excessive heat. The lower the e.m.f. applied, the longer the time required to produce break-down under a given set of conditions.

(6) It follows from (5) that if the temperature is kept low, either by providing good ventilation or by artificial cooling, the stress required to cause break-down in a time test will be much greater than if the material is not so cooled.

(7) The actual temperature measured in most fibrous materials before break-down occurred was usually 175° C. or more. In no case did a break-down occur directly at the point where temperature measurements were being made, and the temperature at the breaking down point was probably higher than measured, especially as the rise in temperature seemed to be very rapid at the point of break-down just before this occurred.

(8) With a given stress, the initial and surrounding temperature has much to do with the rise. This is due to the fact that the loss in the material increases rapidly with the temperature. For example, if the material and surrounding air are at 20° C. and the stress applied is 20,000 volts, the rise in temperature will not be nearly so great as if the initial and surrounding temperature is at 80° C. Tests have shown that break-down frequently results under the latter conditions from a stress that would not injure the material under the former conditions.

Fig. 1 gives some of the characteristic curves of rise in temperature in insulating material when subjected to high potential stress. Curves A, B and C were taken on a sample of untreated material which was quite porous and capable of absorbing moisture from the air. In this test the material was well-ventilated, so that any moisture could be quickly dissipated. The temperatures given are those actually measured, but probably do not represent the highest point reached in the material. Curve A shows the effect of moisture. The temperature rose very rapidly, reaching a maximum, then fell, and at last became stationary. Curve B shows the effect on the same material after very thorough drying. Curve C shows the increased temperature due to a slight increase in the stress.

Curve D at the upper right hand corner of the figure, shows the

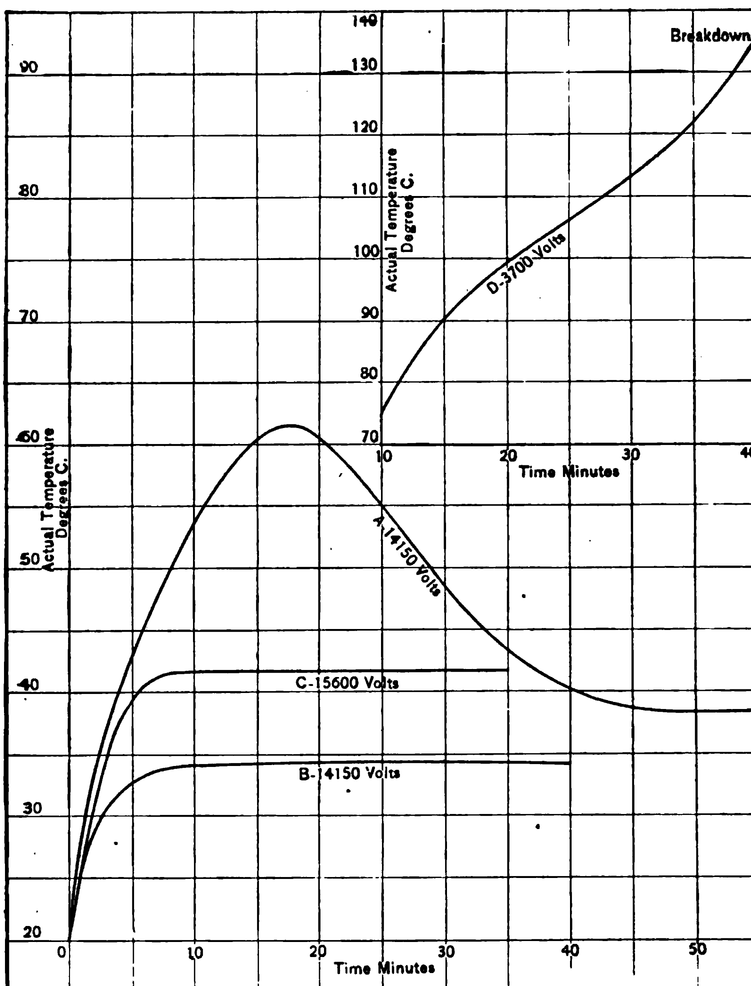

Fig. 1.—Showing Increase of Temperature in Insulating Material due to Stress.

rise in temperature in treated material when poorly ventilated, and the test continued until break-down resulted. Break-down in this particular test occurred at a point about 4″ from the thermo-junction when the measured temperature reached 135°

C. It is probable that the temperature measured was considerably lower than that reached at the point of break-down. The temperature of the surrounding air in this test was kept at 80°C. This curve shows the tendency of the temperature to become constant, but at a point slightly over 100° C. the loss becomes so great that the heat cannot be dissipated as fast as generated, hence the change in direction of the curve and final break-down. In numerous tests the material was found to be badly charred on the interior, without break-down having resulted. The curves shown are characteristic, and are of the same form as many others that have been taken.

Variation of Loss Due to Variation of Temperature.

The measurement of the energy loss due to high potential stress in a reasonably small sample of insulating material, presents a rather unusual problem. The voltage is high, the current small and the power factor very low. In many of the tests referred to in this paper, it was necessary to measure with some degree of accuracy, losses of less than 100 watts at an e.m.f. of 20,000 to 40,000 volts,at various frequencies, with a power factor less than 0.1. The commercial instruments on the market are totally unsuited for this work.

Many of the measurements to determine the points under discussion were made by means of a calorimeter. This calorimeter consisted of a tank filled with mineral oil, in which the sample was placed. Calibration was effected by passing direct current through a resistance coil immersed in the oil and noting the rise in temperature of the oil, due to various amounts of energy absorbed. The rate of cooling from various temperatures was also carefully taken and was made use of in deducing many of the results. Great care was exercised to secure uniform temperature throughout the body of the oil by mechanical stirring, and the calorimeter was carefully shielded from drafts to prevent variation in the rate of cooling.

The material for these tests was usually built up in the form of a small condenser, with ventilating spaces between the plates, so that the temperature could be kept as nearly uniform as possible throughout the mass of the material. In the determinations of the variation of loss due to variation of temperature by the calorimeter method, the whole body of oil and insulation was brought up to some constant temperature, then the high potential stress applied. The rate of heating or cooling, as the case might be, due to the loss in the insulation being greater or less than required to hold the calorimeter at this constant temperature, was then noted and the actual loss was derived by the use of the calibration curves of the calorimeter. These tests required great care, were very tedious and many corrections were required in deducing the results.

After a considerable amount of work had been done by the calorimeter method, a static wattmeter[1] was constructed and the work continued with this instrument. With this wattmeter, which was admirably suited to this work, a complete curve could be taken in the time required to determine a single point by the calorimeter method. It was a source of considerable satisfaction to find that the calorimeter and wattmeter methods checked each other with a very fair degree of accuracy, especially considering the nature of the materials on which the measurements were made.

In Fig. 2 are given curves which are characteristic in form for the increase in loss due to temperature. These particular curves were taken by the wattmeter method on a sample of material which had been used for some months for other tests and was known to be in the very best condition as regards moisture, etc. This general form of curve has been found to hold for all materials tested, although the rate of change of the loss and the amount of the loss per unit volume may be very different for different materials and even for the same sample of material under different conditions.

This series of tests has shown:

(9) The energy loss in fibrous material increases with temperature, the rate of increase in the loss being greater than the rate of increase in the temperature.

(10) The rate of increase depends upon the kind of material and on its condition with respect to dryness, etc.

(11) The local heating found in a mass of poorly ventilated material is due to a greater initial loss in one portion, causing increased heating, this in turn causing greater loss, etc., until the temperature finally reaches a point at which charring and breakdown result.

(12) These curves show that the rate of increase of loss is greater at high than at low temperatures, therefore giving the

1. For description of this instrument see paper entitled "The Static Wattmeter in Commercial Measurements," presented at this meeting by Mr. Miles Walker.

reason for the greater rise in temperature with a given stress when the initial temperature is high than when it is low.

Other tests have shown:

(13) That the loss increases very rapidly indeed, when tem-

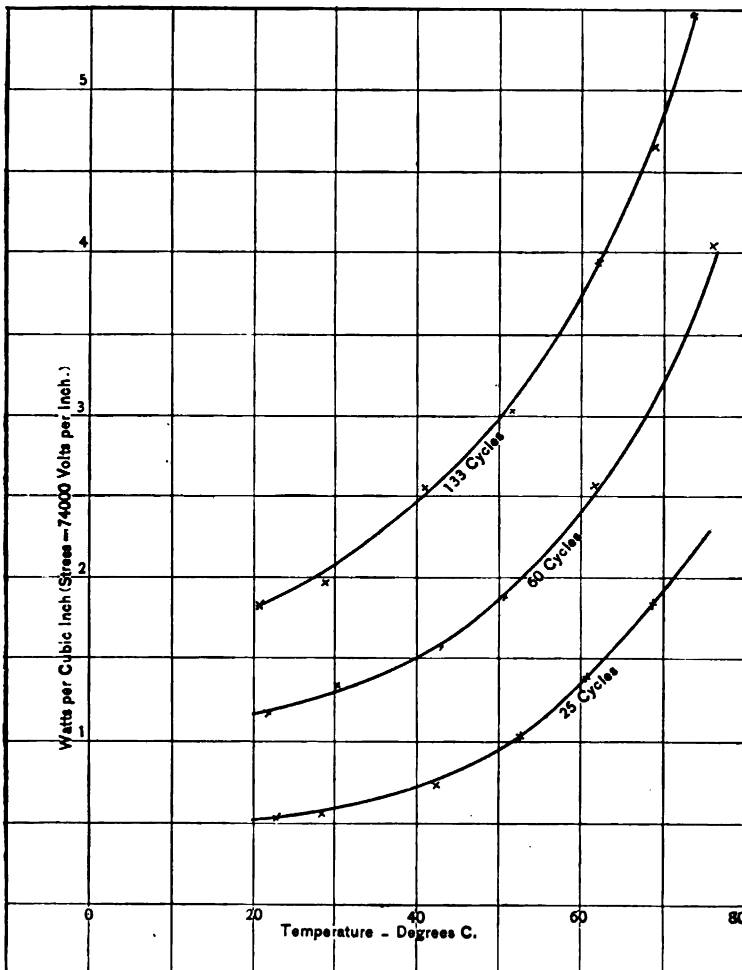

FIG. 2.—Showing Variation of Loss in Insulating Material due to Temperture and Frequency.

perature approaches the charring temperature of the material.

(14) Losses as great as 5 watts per cubic inch have been measured in material before serious injury resulted, due to

charring. A loss considerably less than this will, however, char the material in time, unless special means are taken to dissipate the heat generated.

(15) It follows from considerations of rise of temperature due to increased stress, and increase in loss due to increase in temperature, that *a long continued test at high stress may seriously injure the insulation of a piece of apparatus without this being made apparent by the test.* This has often been spoken of as " straining the insulation " for want of a better term, the idea being that this was in some way analogous to the straining of a piece of metal beyond its elastic limit. It is probable that this " straining " is always due to charring.

Variation of Loss Due to Variation of Voltage.

As will be seen from the foregoing, there are two conditions, to be considered under this head: (a) Variation of loss with voltage, the temperature remaining constant; (b) Variation of loss with voltage, the temperature varying, due to the loss itself.

(*a*) *Variation of Loss with Voltage, the Temperature Remaining Constant.*—If the loss in a dielectric is due to partial conduction, as has been stated by Hess, it is to be expected that this loss will vary as the square of the voltage applied. This fact was shown experimentally by Mr. Steinmetz in 1892, and the law announced by him at that time was as follows:

" The energy consumed by the dielectric medium under alternating electrostatic strain is directly proportional to the square of the intensity of the electrostatic strain."

In his original note on this subject, Mr. Steinmetz stated that this law was not true beyond a certain limiting strain and was not true at lower strains until the dielectric had been allowed to recover by standing for some hours. This phenomenon noted by Mr. Steinmetz was in all probability the effect of temperature on the dielectric of his condenser. This shows that in tests of this kind, care must be taken to prevent the temperature changing during the test and thus masking the results sought.

(16) The tests made, show a fair agreement with the law above noted, the increase in loss usually being slightly greater than the square of the e.m.f.

A specific example illustrating this case is given later in some measurements made on the armature insulation of two of the 5,000 k.w. alternators built by the Westinghouse Electric & Manufacturing Company for the Manhattan Railway Company.

(*b*) *Variation of Loss with Voltage, the Temperature Varying, Due to the Loss Itself.*—It has already been shown that there is a rapid increase in the energy loss in a body of insulating material due to increase of temperature; also that the energy loss varies approximately as the square of the voltage when the temperature remains constant.

(17) It follows, therefore, that under the usual conditions of high potential stress the loss will increase more rapidly than the square of the voltage, because the temperature increases at the same time.

(18) The rate of this increase will depend on the facility with which the material can get rid of its heat, and on the length of time the material is subjected to each successive stress in carrying out the test.

(19) It will also depend on the initial temperature of the material and the temperature of the surrounding medium.

It will be seen that many of the conditions named under variations of temperature due to variation of stress apply to this case.

Variation of Loss Due to Variation of Frequency.

Like all the other phenomena described in this paper, it has been found very difficult to make check measurements on the losses of a large number of samples of materials at different frequencies and deduce a mathematical law from the results. In Fig. 2 are shown three curves giving results on a single sample of material tested at 25, 60 and 133 cycles.

(20) It will be noted from these curves that the rate of variation for this particular set of tests is approximately in proportion to the frequency at the lower temperatures, but follows a different law at the higher temperatures.

(21) In some other tests which were carefully made, the loss varied approximately as the square root of the frequency, but these results are not sufficiently well substantiated to announce as a law.

Energy Loss in the Insulation of Large Alternators.

Some measurements recently made of the energy loss in the armature insulation of the 5,000 k.w. alternators built by the Westinghouse Electric & Manufacturing Company for the Manhattan Railway Company, should prove interesting in this connection. These tests were made to check some of the results obtained on a smaller scale and to give some of the conditions which exist when very high potential tests are made on large, high voltage apparatus.

These alternators are wound for a terminal e.m.f. of 11,000 volts, the winding being 3-phase star connected. In the design of the insulation, special attention was given to securing great dielectric strength, low dielectric loss and permanency under all conditions of operation. Preliminary tests in the factory had shown a dielectric strength of 80,000 to 90,000 volts for short applications of e.m.f. and a very small rise in temperature for a 30-minute test at 35,000 volts.

The tests to be described were made on two of these alternators after they had been installed ready for service. The accompanying diagram, Fig. 3, shows the connections of the various apparatus used. The primary current for the testing transformer was obtained from 350 volt (25 cycle) mains, and voltage regulation was by means of a large water rheostat in series with the primary of the testing transformer. The testing transformer had a capacity of 250 k.w. at 40,000 volts, loops being brought out to give steps of 5,000 volts on the high tension winding. Three instruments were used to measure the voltage: a direct reading voltmeter across the primary of the transformer, a voltmeter in series with a high resistance across a part or the whole of the high tension winding, and a static voltmeter across the high tension winding. Current was measured by means of a specially calibrated low-reading ammeter, with a series transformer arranged to multiply the current by 4. The small bank of lamps shown was used as a rough check on the ammeter readings.

The losses were measured by means of the static wattmeter referred to earlier in this paper. The quadrants were connected across a variable, previously calibrated resistance and the needle connected to the 10,000-volt loop on the high tension winding of the testing transformer. The deflection of the needle was read by a telescope and scale. The wattmeter was calibrated by using the voltage across one lamp in a series of four on 500 volts direct current. It may be said for this instrument that after standing over two months in the power-house between tests, the constant had changed less than two-thirds of one per cent.

During the tests, one terminal of the testing transformer was connected to the three leads from the armature winding and the other terminal to the frame and to ground. The measuring instruments were connected in the grounded side as far as possible. The temperature of the windings was taken by means of a thermometer near the floor line of the machine. Loss measure-

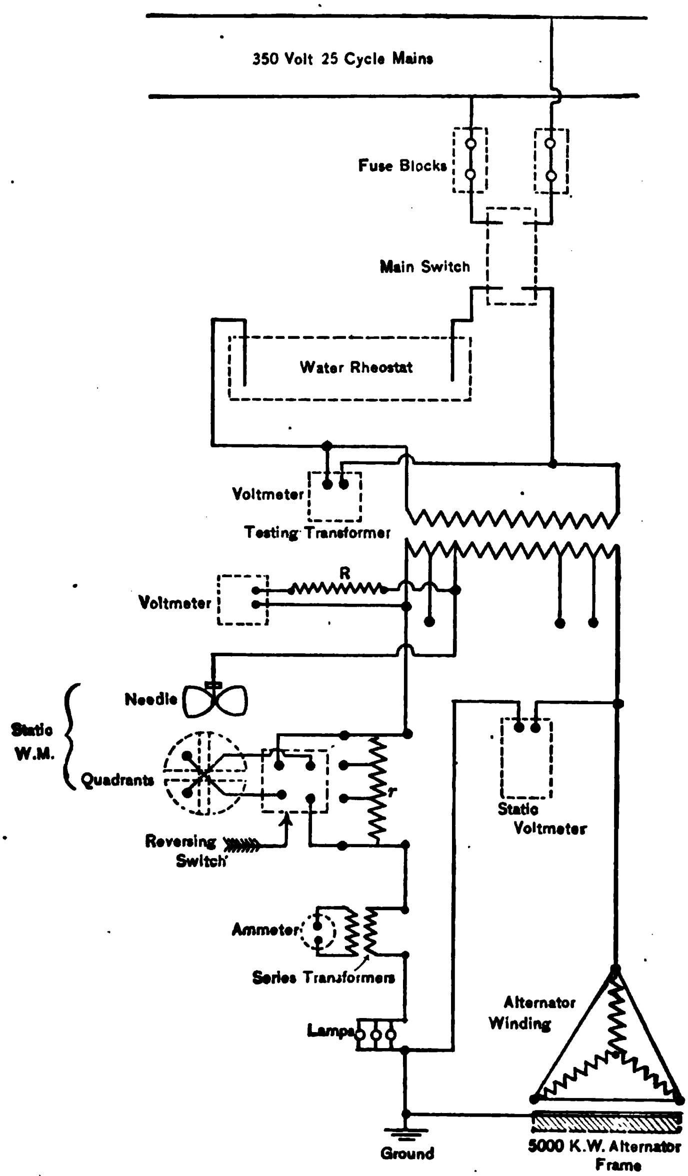

FIG. 3.—Diagram of Connections for Measurement of Insulation Losses of 5,000 K.W. Alternator Armatures.

ments were made at approximately 5,000, 10,000, 15,000, 20,000 and 25,000 volts.

The accompanying curves, Fig. 4, show the results of these measurements. Curve A was taken on alternator No. 7 and B on No. 6. The temperature of the windings on No. 7 at the time of test was approximately 21° C. and on No. 6 approximately 31° C. These temperatures are only approximate as there must

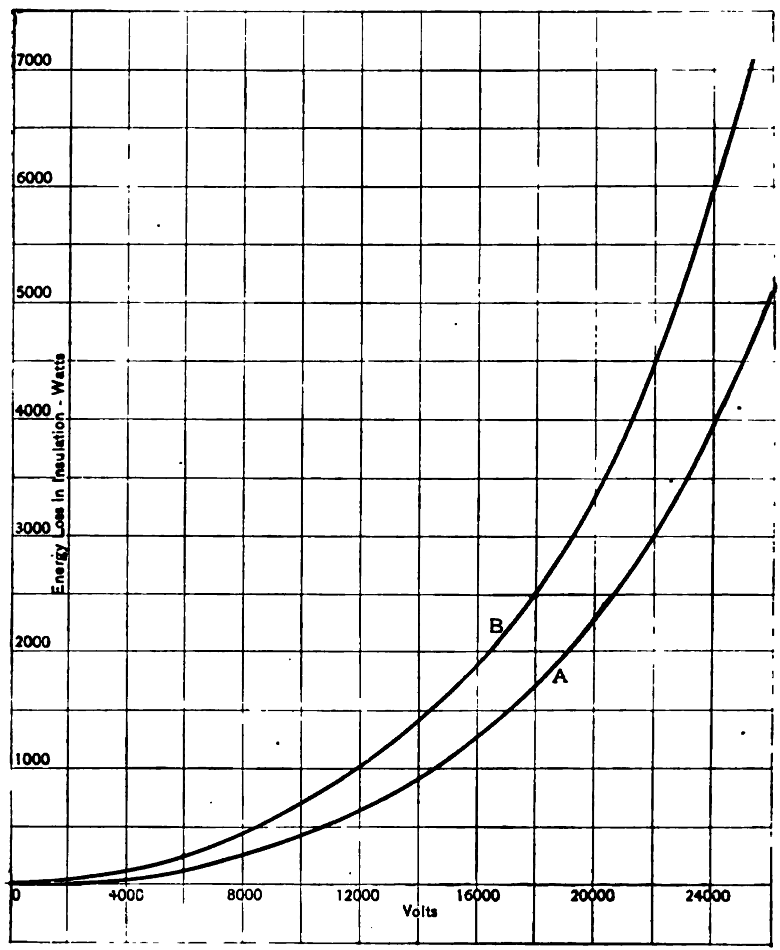

FIG. 4.—Showing Energy Loss in Insulation of 5,000 K.W. Alternator Armatures.

necessarily be some difference in temperature in different parts of a machine of this size, where the parts of the winding are so widely separated from each other. Unfortunately, it was not found feasible to make tests on one machine at different temperatures, and even if this had been done, it would have been difficult to make accurate measurements of the temperature, for the reasons stated above.

The amount of insulating material under stress in these tests was approximately 19,500 cubic inches, this giving a maximum measured loss of 0.35 watts per cubic inch at 25,000 volts. At a stress of 11,000 volts between the windings and the frame, the loss measured was less than 1 k.w. total for the machine. The loss in the insulation during normal operation of the machine will be much less than this, as the maximum stress to ground when circuits are statically balanced will be approximately 6,400 volts at the lead end of the winding and 0 at the neutral point. As the loss increases approximately as the square of the voltage, the total loss due to normal operation will be only one-third of the loss at a stress of 6,400 volts applied between the windings and the frame. The total loss, therefore, under normal conditions of operation and at the normal temperature at which the machine will run will be less than ½ k.w., which is entirely negligible both as regards its effect on the efficiency of the machine and on the rise in temperature. On the other hand, it will be seen that the loss at a stress of 25,000 volts is a very measurable quantity, and the form of the curve shows that this will increase very rapidly as the stress is increased above this point.

From these curves we may see:

(22) The variation in loss due to variation of stress is slightly greater than the square of the stress applied. This increase in rate cannot be due to temperature, as the total loss is not sufficient to cause appreciable heating, and measurements made during a 30-minute application of 25,000 volts did not show any variation in the loss.

(23) The increased loss at the higher temperature was somewhat greater than was to be expected from measurements made on small samples of material. This may be due to an actual difference in the loss of the two machines, or to the fact that it is nearly impossible to get any accurate measurement of the average temperature of the insulation of a machine of this size.

(24) The loss at 25,000 volts is not sufficient to cause any injurious heating, even in a long-continued test.

(25) The rate of increase of loss indicates that at a point not far above 25,000 volts the loss would be sufficient to cause heating and possible damage to the insulation if the stress were applied for any considerable length of time.

It is not possible to state in general terms the safe limiting stress which can be applied in a time test to a piece of high potential apparatus, but measurements of the loss and a knowledge of the materials used will give the designer some idea for any particular machine. Such tests are very rarely necessary and should not be required on ordinary commercial apparatus. When a time test is required, it should be at a voltage much below the dielectric strength of the insulation under test.

In conclusion, the author wishes to state that while the work already done has been considerable, there is much more to be done in this line and it is hoped that many of the points now more or less obscure and uncertain may be cleared up in the near future. There are yet many materials to be investigated and experimenters who have the time and patience will find this a fertile field for their labors.

Finally, I wish to acknowledge my indebtedness to my co-workers, Mr. P. H. Thomas and Mr. Miles Walker, for much data and many valuable suggestions in connection with the investigation of this subject; the former particularly in connection with the extensive calorimeter tests carried out by him and the interpretation of their results, and the latter in connection with various temperature and wattmeter measurements. I am also indebted to Mr. H. G. Stott, Superintendent of Motive Power of the Manhattan Railway Company, for the facilities placed at my disposal for making the measurements on the 5,000 k.w. alternators in the above company's power-house.

DISCUSSION.

Papers by Percy H. Thomas, Miles Walker and Charles E. Skinner, at Great Barrington, June 20, 1902.

DR. EDWARD L. NICHOLS:—I should like to say in reference to this last paper, that in some recent observations by Dr. Shearer which were intended for quite a different purpose, that of studying the change of length of tubes subjected to electrostatic pressure either alternating or direct, our conclusions with reference to what took place were very similar to those described in this paper. It was found that before the breaking down of the dielectric, this heating effect was noticed, even in glass and rubber, making it exceedingly difficult to carry the tests up to the neighborhood of the breaking point. I should say that the observations which were made were entirely corroborative of the view just suggested; that the breaking down of the dielectric even where the stress is direct and not alternating, was to be ascribed to heating. It seemed to be a mechanical breaking down, due to the extreme local heating of the dielectric, but in no case a rupture traceable to the mechanical forces of the electrostatic field itself. I mention these observations because they were made with the direct electrostatic stress, and not with alternating potentials, and may serve therefore, to broaden and make more general the conclusion reached by the author of the paper to which we have just had the pleasure of listening.

MR. CHARLES F. HOPEWELL:—I would like to ask whether the author has made any tests on underground cables.

MR. SKINNER:—I know of no test made directly for that purpose, but I think the results are entirely applicable to the insulation of such cables.

MR. W. S. ANDREWS:—I should like to ask Mr. Skinner if he has ever noticed the effect of oil on mica, in the way of weakening its resistance to puncture. I once made some tests in this line and found that a sheet of mica which would resist a pressure of 10,000 volts for an unlimited time in air would break down almost instantly under oil at a pressure of 4,000 or 5,000 volts.

MR. SKINNER:—I have not made tests under oil, but I have done so with a film of oil on the surface of mica and found that to be the result.

MR. W. S. ANDREWS (*Communicated after adjournment*):—The following tests were made with alternating current delivered at 118 volts, 60 cycles. The voltage was raised by a small step-up transformer with necessary regulating devices, and measured by a G. E. static voltmeter reading up to 10,000 volts. A good quality of clear white India mica was used, a dry sheet of which, .002″ thick, would stand a pressure of 8,000 volts for an indefinite time in air.

The accompanying sketch (Fig. 1) shows the general arrangement of the testing apparatus. A and B are two brass rods supported by a piece of hard rubber, C, and bent towards each other at right angles at their lower ends. One of these rods terminates in a brass disk about $\frac{3}{8}''$ diameter and the other rod is finished with a rounded point touching in the center of ths disk. This rounded point rests against the disk with sufficient pressure to

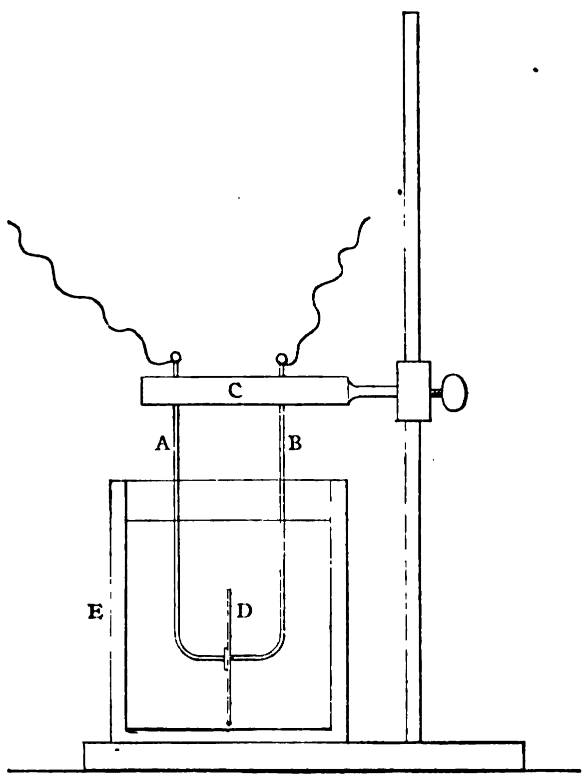

FIG. 1.

support the piece of mica, D, that is to be tested. These parts are attached to a stand so that the holder with mica may be lowered into a vessel, E, containing oil. Preliminary experiments were made with various kinds of oil, but no difference in results could be observed, so it was decided to use a good quality of transil oil for the present tests.

The figures in the following table show the average puncturing voltage derived from a number of tests made on each thickness of mica used.

THICKNESS OF MICA.	AVERAGE PUNCTURING VOLTAGE.
.001"	3,800
.0015"	4,500
.002"	4,600
.0025"	4,750
.003"	5,300
.004"	5,570
.00475"	5,950
.005"	6,050
.006"	6,700
.0065"	6,930
.007"	7,220
.0075"	7,400
.008"	7,700
.0085"	8,550
.01"	8,900

It is not necessary to place the mica under the oil in order to reduce its puncturing resistance. If a piece of mica, say .002" thick, is supported in the holder shown in sketch, the holder and mica being quite free from oil, the pressure may be raised to about 8,000 volts, and, if the mica is of good quality, it will stand the strain indefinitely, but if a drop of oil is applied to the blunt metal point, the mica will be instantly punctured.

It is curious that oil does not seem to produce any weakening effect on artificial insulators, such as paper coated with boiled linseed oil, copal varnish, etc. The results of many tests show that the resistance to puncture of these materials remains about the same, whether tested in air or under oil.

DR. PERRINE:—Mr. Thomas's paper is very interesting to me. In some of the installations with which I am familiar, there have been installed an enormous number of gaps, and they have been found to fail utterly when certain conditions of discharge were produced. This is a decided step in advance that Mr. Thomas has made. It seems to me there is something still to be done in that direction. Mr. Thomas depends on rupturing the current, if I understand the theory of the paper, by the introduction of the shunt resistance in addition to the series resistance, and that means that the shunt and series resistance combined must be comparable to the total resistance of the circuit. It is possible to do that, but that amount of resistance may run up to a very large amount in many cases where we have in series with the generator a long-distance line in which the resistance has become considerable. Then there is another point that seems to me not to be covered by this particular device, and that is the fact of the change of frequency which occurs when the lightning arresters discharge, and the line is short-circuited through the lightning arresters. For power-house conditions I should be inclined to think that Mr. Thomas's plan would be applicable, because there we have simply the inductance of the machine to take care of, and the resistance if made high enough will take care of every form of the charge, but when we put the same apparatus at the end of a long line or end of a heavy cable, we get entirely changed conditions. Mr. Thomas's paper is one of the most difficult to raise any points of objection to, because it is an experimental paper, and a man who has performed the experiments knows what his apparatus will do. At the same time I have had a recent remarkable instance of what I suppose is resonance in a cable line going into a substation where there was a break in the wire in the cable, opening only after high currents began to pass. The cable was closed, and moderate currents flowed. When large currents began to flow there was an arc produced within the cable,

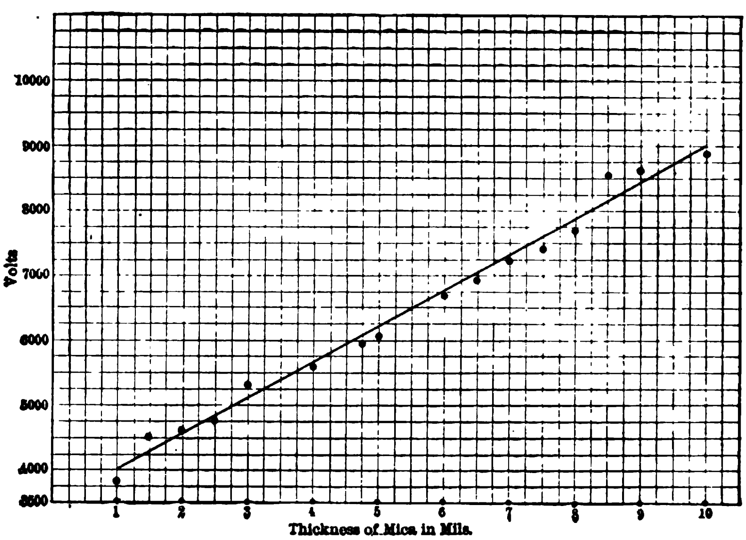

FIG. 2.

and the effect of that was to let such currents through, that the fuses were blown out and fuse blocks destroyed, and switchboards blown out, and an appearance of short-circuited currents entirely beyond the capacity of the machine to produce. If the self-induction of the machine had not been counteracted by the capacity of the cable that is producing this resonant condition, by reason of the fact that the arc was of an immensely higher rate of alternations than the normal rate of alternations of the machine, allowing currents to flow by, putting the line in the condition of being for those frequencies practically distortionless. I should think the same effect would be found in producing an arc between the gaps of an arrester at the terminal of a long line, or where we had long cables. This can hardly be overcome by any ordinary value of non-inductive resistance, and it might be necessary to carry on this work a step further, using possibly a number of selective resistances, some of which would stop the normal rate of frequency, and others would be resistances when the frequencies were very much increased. That is a condition that we are likely to meet in all lines where we have large capacity in series with generating apparatus or other apparatus where the inductances are large; and whether the arc is of true alternating character in the small gaps of a lightning arrester, I don't know; but if it is of that nature, we undoubtedly would have under certain circumstances the induction of the circuit; and I would be inclined to think that in such circumstances these arresters will not act, and until this system has been thoroughly applied to such cases, I think it will be impossible to say that the result that Mr. Thomas has reached is the complete solution.

Regarding Mr. Skinner's paper, I notice in the curves on Figs. 2 and 4 a remarkable resemblance to similar curves that have been derived from high-potential tests of long cables, and particularly with the curves that are derived in working with gutta-percha at varying temperatures. The energy loss at varying voltage and varying temperature seems to be, from the appearance of the curves, almost the same as the character of curve which is obtained with gutta-percha. Now the work with cables has also shown the correctness of Mr. Skinner's observations, that a slight amount of moisture in the insulation will materially increase the heating, and that heating of this character almost invariably results in final breakdown; and the fact that the heating is greater than the $C^2 R$ loss, has also been observed in cables, and my idea has always been that that is due to electrolytic conduction. In experiments with cables that are at all damp, with a direct current, I have invariably found that where a cable was subjected to high-potential direct-current strain, and then disconnected, that cable acting as a storage battery would furnish a current for a very considerable length of time. In cable working I found many instances similar to that, and invariably where I found the temperature of the insulation rising beyond what it should attain, due to the strain from the potential applied, that it was due to the presence of moisture, that there was a distinct appearance of electrolytic conduction through the cable, heating it more than would be reasonable to suppose, and ultimately breaking it down. Mr. Newbury, the electrician of the Roeblings, has also found a number of interesting things in connection with thoroughly dry cables. His experiments seem to indicate that with fibre cables you can increase the dielectric strength of the cable by increasing the thickness of the insulation, up to a certain critical e.m.f.; beyond that point the cable seems to break down at almost the same potential, irrespective of increase in thickness; and in discussion with him I came to the conclusion that it was impossible to so thoroughly saturate the fibre cable that there are no vacuous spaces in the insulation, and in certain cases those vacuous spaces distinctly acted as a conductor, and beyond those potentials it was not possible to use that type of insulation. The same thing we generally found in breaking down rubber cables; that in nearly all instances where the rubber cable was broken down below the normal e.m.f., which should break the dielectric, that there were vacuous spaces within the rubber, not necessarily any moisture present, but simply rarefied gas. Through vulcanization of the cable the air would be heated, a small bubble of air would increase to a large one, the rubber became vulcanized, and would not contract when the temperature was relieved, and that would make a vacuous space which would invariably locate the breakdown of the cable at and below the normal dielectric strength represented by the thickness of the insulation and character of the material; and it seems to me that this work of Mr. Skinner's has shown very clearly that for perfect insulations we can gather a great deal of valuable information by comparing the work that has been done by the cable engineers in the very careful study which they have made of gutta-percha. Vulcanized rubber has never been studied so carefully, at any rate studies have not been published, because vulcanized rubber is such an indefinite material; but gutta-percha is a perfectly definite material, has been carefully studied, and seems to bring out an entire confirmation of the class of results that Mr. Skinner has brought before us.

PROF. THOMSON:—I am inclined to agree with Dr. Perrine with regard to the necessity for carrying out tests concerning lightning protection under practical conditions; that is, we must gain our experience not so much in the laboratory with limited appliances, but with our lines. We must look for damage on or from the actual lines, see what caused it, and then attempt to find the remedy. We can, of course, reproduce to a certain extent the conditions by laboratory operations, but when we have a long line with capacity and inductance to take into account, and high potentials in operation, the conditions seem to change the results very materially. In regard to the point which Dr. Perrine drew attention to, the insulation breaking down notwithstanding the increase of thickness, I think there exists a very simple explanation for that. Given the diameter of the wire of the cable, a certain thickness of dielectric surrounding the same, it is manifest that the stress is a radial stress, and most highly concentrated around the wire, and so an increase of thickness may not change the radial stress particularly. It is akin to the fact that with a certain diameter of wire in the air under electrification up to a certain point, the air breaks down near the wire. There is a blue discharge over the wire in the air at certain potentials. The only remedy is to increase the diameter of your metallic portion so as to reduce the gradient of stress, reduce the steepness of the gradient at the wire surface.

DR. PERRINE:—I do not think that explains it altogether, for the reason that experiments were made with wires not smaller than $\frac{1}{4}''$ in diameter. While that is altogether true, it does not seem we are getting up to the point or condition with a $\frac{1}{4}''$ wire and 10,000 volts strain.

PROF. THOMSON:—I agree that it undoubtedly is provoked by some lack of homogeneous character in the dielectric; but my point is you do not gain such a great deal by the addition to thickness; that the stresses remain high on those weak points. In the same way, the mica plate being broken down when covered with oil or an oil film, the tendency there is, the oil being thick and thin in spots, to produce again the radial stress upon the thin portion—the concentration of stress will be at the portion where there is no oil, or at least where the oil may be the thinnest, and there is protection of the surrounding area by the layer of oil.

DR. PERRINE:—That is invariably true with any compound dielectric.

MR. THOMSON:—Yes, it is undoubtedly.

MR. MAILLOUX:—It was pointed out in a paper read before the Institution of Electrical Engineers in London by Mr. O'Gorman, that sometimes a piece of very highly insulating material placed between two conductors subjected to a high e.m.f. would, instead of increasing the resistance to puncture, actually decrease it. The explanation given in that paper is that a piece of glass, for instance, while it is a high insulator, yet is really a lower insulator than dry air, and consequently it tends to really increase the difference of potential across the actual air gap remaining; in other words, if there be no glass, we have a certain fall of potential between the two points, but if we put a piece of glass there, which really acts as a high resistance conductor, the effect is the same as if the actual difference of potential were increased. This may perhaps have some relation to the question here discussed.

There is another point upon which I would like to have some information. I had occasion about five years ago to make some experimental tests in a rough way of a certain insulating material. The experiments were conducted at a laboratory in Vienna by Professor E. Grau and myself. The material was a sort of resinous compound which became soft at a certain temperature. This material was placed in thin sheets between two discharge points, connected with a Holtz machine, using a by-pass spark gap of lower potential in the well-known way, so as to control the voltage applied to the sheet of material at the point to be tested. Although the temperature at which this material resisted puncture was quite high, it was observed that in every case before the puncture took place there seemed to have been a thinning action, as if the material was mechanically brushed off radially from the point of greatest stress, and pushed away on each side, the action being quite similar to the displacement or the flow of metal by the action of a die—or other perforating instrument—when we try to perforate a piece of lead with an awl for instance, when the metal flows or is displaced sidewise. There seems to have occurred an action quite similar and comparable to this; and the conclusion which Professor Grau and I came to, at the time, was that the puncture resulted not only from the increase of temperature, and the consequent actual decrease of the dielectric strength, but also from the actual thinning of the plate. In some cases a thinning in a plate of three or four millimetres thickness occurred to the amount of as much as half a millimetre before the puncture took place. I would like to know whether any similar effects have ever been observed in any other materials which are not viscous, at such low temperature. I think that in any homogeneous substance which becomes softer as the temperature increases, we should have an analogous phenomenon. In this case, the phenomenon seemed to be more of a mechanical character, than of a chemical, electrolytic or other similar nature.

MR. THOMAS:—I would like to make one point in regard to Mr. Skinner's paper. His conclusions are specially valuable as they represent the results of a number of years of practical commercial work, and of a great many tests made under a great many different conditions, a great many different times, by different people and different methods, and the conclusions from all those tests are summed up and brought into a general law. There has been a great deal published in a fragmentary way on this subject by men who have tested a few samples, may be a good many samples of one particular object; and taken all together, something can be derived from these results; but they are not to be compared with the results which are obtained by Mr. Skinner by years of experimenting on practical materials, under working conditions. I would like to bring out one point relating to the continuation of Professor Thomson's discussion in regard to the breakdown of these cables. I think it was Mr. O'Gorman in a recent paper before the British Institution who stated that a cable can be made with materials of different conductive capacity placed on different circles around the core and in this way the strain can be made equal on the outer portion or the inner portion.

MR. WM. MAVER, JR.:—In regard to the point raised by Dr. Perrine, that the pressure resisting quality of the cable does not continue to increase with the thickness of the insulating material, I have heard the explanation offered that it may be due to the fact that, as we all know—I presume the Doctor has referred to oil saturated cables—it is necessary in these fibrous cables to expel the moisture very thoroughly, and to do that the cables are dried in a heating oven, and it has been observed that when the insulation exceeds a certain thickness the amount of heat necessary to drive out the moisture is so great or so long continued that it has a detrimental effect upon the outer layers of the insulating material; and on the other hand, when the cables are then plunged into the insulating compound, the thickness of the material does not permit the oil to permeate the entire mass of the fibrous material, and therefore its dielectric strength is not so great as might be expected in proportion to the thickness of the insulating wall.

PROF. P. B. WOODWORTH:—I have found when the dielectric strength was very low, a transformer placed in circuit would break down. I tried to account for this condition, by using commercial oil where I obtained a dielectric strength of about 16, put it into a transformer and found a dielectric strength of 2. I carried on quite a series of investigations, tried to find out why the oil dropped from 16 to 2, and for a long time could find no clue to it. I came to the conclusion that there was enough water in the transformer at the time the oil was put in, to furnish sufficient moisture to diminish the dielectric strength. I tried some experiments, and found all I needed was something less than 9/100 of 1 per cent. of water in the transformer oil to change the dielectric strength from 16 to 2. The oil used in the transformer was regular commercial oil. I then carried on some investigations to ascertain where the water came from. I made some calculations as to the amount of moisture there was in the air at the place, and the amount of change in the temperature that would be necessary to form a deposit in the transformer sufficient to supply all the water required. I found a change of temperature of about 10°C. was all that was necessary to form the film on the plates in the transformer, sufficient to change the dielectric strength. It seemed to me, when the transformer is sent out to be filled with oil, great care should be taken that the transformer is warmed up before the oil is sealed in; the immense surface permits a deposit of moisture.

PRESIDENT STEINMETZ:—I can corroborate the statement that the disruptive strength of oil is very largely affected by a trace of water. That is one of the most important matters where oil is used for high-grade insulation. If there is no further discussion, I call upon Mr. Thomas to conclude his paper.

MR. THOMAS:—I have only a few words to say, though the subject might be discussed almost indefinitely. It is very true, as President Steinmetz, Professor Thomson and Dr. Perrine stated, that experiments with trial plants of large capacity is the only certain way of determining the full effect of any such apparatus. It may turn out there is a difference on whichever end of the line the arresters are placed. In any case, however, we are to look for favorable results as regards oscillations from the use of resistance, for though the resistance may not always be sufficiently great to overcome all tendency of a circuit to oscillate, yet it is in the right direction and at least as regards resonance phenomena, we are better off with it than without it. I feel sure, however, that our troubles will not be increased even on the largest lines and highest voltages, by the presence of the arresters, provided they are properly designed.

In regard to one of the points our President brought out I will say that I should have made it clear myself that we have as a result of using the series and shunt resistances, double the number of gaps to suppress the generator arc. This principle can theoretically be carried further; if we have three times the number of gaps necessary to withhold normal voltage, the second part shunted by a high resistance and the third by a low resistance, we can without increasing the voltage necessary to cause discharge, have three times as many gaps effective as with plain series resistance, and so on. Practically, however, such an arrangement involves rather too much complication.

The discussion on Mr. Skinner's paper suggests a point that I wish to bring out. Very possibly the energy loss in commercial insulating material is due to local high-resistance conduction within the material. If this is true, we should not expect the law that a single cycle has always the same loss of energy in it to hold strictly, independent of frequency. For if we assume local high resistance conductors in the midst of the material, we can analyze the phenomena in this manner; if the local circuits were perfect conductors, they would have the effect of reducing the thickness of the dielectric; if perfect insulators, they would have no effect at all, but as they are somewhere between perfect conductors and perfect insulators, their effect will be intermediate. When the frequency is very low, there will be ample time for all necessary charge to flow through the high local resistances so that it acts nearly as a perfect conductor. If, however, the alternations are very rapid, and a high internal resistance will not allow time for any appreciable charge to flow, then the result would be that local circuits will act nearly as perfect insulators. There will be a certain $C^2 R$ loss in either case, and a difference in the effective thickness of material, so that frequency will evidently have a very decided effect on the energy loss per cycle. Experimentally it is found that differences in temperature, differences in frequency, differences in amount of moisture, etc., affect very materially the loss per cycle.

It is very desirable, of course, that we learn how to build dielectric material perfectly homogeneous and in the very best possible condition electrically, but we must always bear in mind the fact that even though this ideal is attained, it will be very difficult to maintain; the material must be carefully protected, so that no moisture or other harmful matter can be absorbed. The difficulty of maintaining the ideal condition in commercial practice may prevent our making full use of a perfect dielectric, even if we are enabled to produce one.

Mr. Skinner:—I have but a word to say further about Mr. Walker's paper, and that is this, that the author considers, I believe, the chief points in the paper the simple method he has given for calculating the torque on the needle and the elimination of the A^2 term in the formula.

In regard to my own paper, I may say that while the investigation of a theoretically perfect insulator is of very great interest, it has been of infinitely more importance to us to take the insulating materials that we are compelled to use in actual practice, and to determine their characteristics, and to find out just how they would act under normal operating conditions. In regard to the point raised by Mr. Mailloux, I may say that I have frequently noted an actual mechanical rupture, principally in connection with some tests of glass under oil. In some instances I found actual chipping of the glass to such an extent that pieces as large as pin heads were scattered over the surface of the glass and a groove was cut, in one instance, half way through a piece of glass which formed one of three or four placed together. This was undoubtedly due to mechanical action.

In regard to the question of water in oil, I may say that this may be detected either by measuring the actual energy loss in the oil or by measuring the dielectric strength. We have found that heating almost any commercial oil increases its dielectric strength. This results until the oil is heated almost to the charring point.

PRESIDENT STEINMETZ:—Gentlemen, before proceeding to the reading of the further papers on to-day's progress I call upon Dr. Kennelly, the Secretary of the Committee on Standardization to submit to us the report of this Committee.

DR. KENNELLY:—The report submitted by this Committee, of which Prof. Crocker is Chairman, differs from the report which was adopted by the INSTITUTE in 1899, mainly in the direction of different paragraphs. A few changes have been made in the report as it was submitted originally, but the principal points of interest are the additions which have been made. I will just run over the report briefly and point out the salient features of addition. A few definitions have been added on the second page.

REPORT OF THE COMMITTEE ON STANDARDIZATION

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[ADOPTED AT THE 19TH ANNUAL CONVENTION
AT GREAT BARRINGTON, MASS., JUNE 20, 1902.]

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To the Council of The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

GENTLEMEN:

Your Committee on Standardization begs to submit the following revised series of recommendations, which embraces the Committee's report of 1899, amended in view of such suggestions and extensions as experience and practice have since indicated to be desirable.

The subjects discussed in these recommendations are such as call for extension and revision from time to time, in view of the rapid advance of electrical engineering.

Yours respectfully,

FRANCIS B. CROCKER, *Chairman.*
A. E. KENNELLY.
JOHN W. LIEB, JR.
C. O. MAILLOUX.
CHARLES P. STEINMETZ.
LEWIS B. STILLWELL.
ELIHU THOMSON.

GENERAL PLAN.

PRELIMINARY DEFINITIONS:

A direct current is a unidirectional current.

A continuous current is a steady, or non-pulsating, direct current.

An alternating current is a current of equal half-waves in successively opposite directions.

An oscillating current is a current alternating in direction, and of decreasing amplitude.

Electrical Apparatus will be treated under the following heads:

I. COMMUTATING MACHINES, which comprise a constant magnetic field, a closed-coil armature, and a multi-segmental commutator connected thereto.

Under this head may be classed the following: Continuous-current generators; continuous-current motors; continuous-current boosters; motor-generators; dynamotors; converters and closed-coil arc machines.

A booster is a machine inserted in series in a circuit to change its voltage, and may be driven either by an electric motor, or otherwise. In the former case it is a motor-booster.

A motor-generator is a transforming device consisting of two machines; a motor and a generator, mechanically connected together.

A dynamotor is a transforming device combining both motor and generator action in one magnetic field, with two armatures, or with an armature having two separate windings.

For converters, see III.

II. SYNCHRONOUS MACHINES, which comprise a constant magnetic field, and an armature receiving or delivering alternating currents in synchronism with the motion of the machine; *i. e.*, having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

III. SYNCHRONOUS COMMUTATING MACHINES:—These include: 1. Synchronous converters, commonly called "converters"; *i. e.*, converters from alternating to direct, or from direct to alternating current, and 2. Double-current generators; *i. e.*, generators producing both direct and alternating currents.

A converter is a machine employing mechanical momemtum in changing electric energy from one form into another.

A converter may be either:

a. A direct-current converter, converting from a direct current to a direct current, or

b. A synchronous converter, formerly called a rotary converter, converting from an alternating to a direct current, or vice-versa.

Phase converters are converters from an alternating-current system to an alternating-current system of the same frequency but in different phase.

Frequency converters are converters from an alternating-current system of one frequency to an alternating-current system of another frequency, with or without change in the number of phases.

IV. RECTIFYING MACHINES, OR PULSATING-CURRENT GENERATORS, which produce a unidirectional current of periodically varying strength.

V. STATIONARY INDUCTION APPARATUS, *i. e.*, stationary apparatus changing electric energy to electric energy through the medium of magnetic energy. These comprise:

a. Transformers, or stationary induction apparatus in which the primary and secondary windings are electrically insulated from each other.

b. Auto-transformers, also called compensators: *i. e.*, stationary induction apparatus in which part of the primary winding is used as a secondary winding; or conversely.

c Potential regulators, or stationary induction apparatus having a coil in shunt, and a coil in series with the circuit, so arranged that the ratio of transformation between them is variable at will.

These may be divided into the following types, or combinations thereof:

1. Compensator potential regulators, in which the number of turns of one of the coils is changed.

2. Induction potential-regulators, in which the relative positions of primary and secondary coils is changed.

3. Magneto potential-regulators, in which only the direction of the magnetic flux with respect to the coils is changed.

d. Reactors, or Reactance coils, formerly called choking coils; *i. e.*, stationary induction apparatus used to produce impedance or phase displacement.

VI. ROTARY INDUCTION APPARATUS, which consist of primary and secondary windings rotating with respect to each other. They comprise:

a. Induction motors.
b. Induction generators.
c. Frequency converters.
d. Rotary phase converters.

EFFICIENCY.

1. The "efficiency" of an apparatus is the ratio of its net power output to its gross power input.[1]

2. The efficiency of all apparatus, except such as may be intended for intermittent service, should be either measured at, or reduced to, the temperature which the apparatus assumes under continuous operation at full rated load, referred to a room temperature of 25° C.

With apparatus intended for intermittent service, the efficiency should be determined at the temperature assumed under specified conditions.

3. Electric power should be measured at the terminals of the apparatus.

4. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the e.m.f., unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, induction generators, frequency converters, etc.

1. An exception should be noted in the case of storage batteries or apparatus for storing energy in which the efficiency, unless otherwise qualified, should be understood at the ratio of the energy output to the energy intake in a normal cycle.

5. Mechanical power in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension, should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of determining them satisfactorily. The brush friction, however, should be included.

Where a machine has auxiliary apparatus, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the machine but to the plant consisting of machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

6. The efficiency may be determined by measuring all the losses individually, and adding their sum to the output to derive the input, or subtracting their sum from the input to derive the output. All losses should be measured at, or reduced to, the temperature assumed in continuous operation, or in operation under conditions specified. (See Sections 26 to 35.)

In order to consider the application of the foregoing rules to various machines in general use, the latter may be conveniently divided into classes as follows:

I. COMMUTATING MACHINES.—

7. In commutating machines the losses are:

a. Bearing friction and windage. (See Section 5.)

b. Molecular magnetic friction, and eddy currents in iron and copper, also $I^2 r$ losses in cross-connections of cross-connected armatures. These losses should be determined with the machine on open circuit, and at a voltage equal to the rated voltage $+ I r$ in a generator, and $- I r$ in a motor, where I denotes the current strength and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

c. Armature resistance losses, $I^2 r'$, where I is the current strength in the armature, and r' is the resistance between armature brushes, excluding the resistance of brushes and brush contacts.

d. Commutator brush friction.

e. Commutator brush-contact resistance. It is desirable to point out that with carbon brushes the losses (*d*) and (*e*) are usually considerable in low-voltage machines.

f. Field excitation. With separately excited fields, the loss of power in the resistance of the field coils alone should be considered. With shunt fields or series fields, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

(*b*) and (*c*) are losses in the armature or "armature losses"; (*d*) and (*e*) "commutator losses"; (*f*) "field losses."

8. The difference between the total losses under load and the sum of the losses above specified, should be considered as "load losses" and are usually trivial in commutating machines of small field distortion. When the field distortion is large, as is shown by the necessity for shifting the brushes between no load and full load, or with variations of load, these load losses may be considerable, and should be taken into account. This applies especially to constant-current arc-light generators. In this case the efficiency may be determined either by input and output measurements, or the load losses may be estimated by the method of Section II.

9. Boosters should be considered and treated like other direct-current machines in regard to losses.

10. In motor-generators, dynamotors or converters, the efficiency is the electric output divided by the electric input.

II. Synchronous Machines.—

11. In synchronous machines the output or input should be measured with the current in phase with the terminal e.m.f., except when otherwise expressly specified.

12. The losses in synchronous machines are:

a. Bearing friction and windage; see Sec. 5.

b. Molecular magnetic friction and eddy currents in iron, copper and other metallic parts. These losses should be determined at open circuit of the machine at the rated speed and at the rated voltage, $+ I r$ in a synchronous generator, $-I r$ in a synchronous motor, where $I =$ current in armature, $r =$ armature resistance. It is undesirable to compute these losses from observations made at other speeds or voltages.

These losses may be determined either by driving the machine by a motor, or by running it as a synchronous motor, and adjusting its fields so as to get minimum current input and measuring the input by wattmeter. In the latter case, with polyphase machines, several wattmeters must be used, arranged so as to measure unbalanced load. The former method is preferable, since the latter is liable to error caused by acceleration and retardation due to a pulsation of frequency, or an inherent tendency to surging.

c. Armature-resistance loss, which may be expressed by $p I^2 r$; where r = resistance of one armature circuit or branch, I = the current in such armature circuit or branch, and p = the number of armature circuits or branches.

d. Load losses as defined in Section 8. While these losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short-circuit and at full-load current, that is, by determining what may be called the "short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

One-third of the short-circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

e. Collector-ring friction and contact resistance. These are generally negligible, except in machines of extremely low voltage.

f. Field excitation. In separately-excited machines, the $I^2 r$ of the field coils proper should be used. In self-exciting machines, however, the loss in the field rheostat should be included. (See Section 7 *f*.)

III. Synchronous Commutating Machines.—

13. In converters, the power on the alternating-current side is to be measured with the current in phase with the terminal e.m.f., unless otherwise specified.

14. In double-current generators, the efficiency of the machine should be determined as a direct-current generator in accordance with Section 7 and as an alternating-current generator in accordance with Section 12. The two values of efficiency may be different, and should be clearly distinguished.

15. In converters the losses should be determined when driving the machine by a motor. These losses are:

a. Bearing friction and windage. (See Section 5).

b. Molecular magnetic friction and eddy currents in iron, copper and metallic parts, also $I^2 r$ loss, due to cross-current in cross-connected armatures. These losses should be determined at open circuit and at the rated terminal voltage, no allowance being made for the armature resistance since the alternating and the direct currents flow in opposite directions.

c. Armature resistance. The loss in the armature is $q\ I^2\ r$, where I = direct current in armature, r = armature resistance and q, a factor which is equal to 1.47 in single-circuit single-phase, 1.15 in double-circuit single-phase, 0.59 in three-phase, 0.39 in quarter-phase, and 0.27 in six-phase converters.

d. Load losses. The load losses should be determined in the same manner as described in Section 12 *d*, with reference to the direct-current side.

e and *f*. Losses in commutator and collector friction and brush contact resistance. (See Sections 7 and 12.)

g. Field excitation. In separately-excited fields, the $I^2 r$ loss in the field coils proper should be taken, while in shunt and series fields the rheostat loss should be included, except where fields and rheostats are intentionally modified to produce effects outside of the conversion of electric power, as for producing phase displacement for voltage control. In this case 25 per cent. of the $I^2\ r$ loss in the field proper at non-inductive alternating circuit should be added as proper estimated allowance for normal rheostat losses. (See Section 7 *f*.)

16. Where two similar synchronous machines are available, their efficiency can be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct-current input, and the direct-current output. This process may be modified by returning the output of the second machine through two boosters into the first machine and measuring the losses. Another modification is to supply the losses by an alternator between the two machines, using potential regulators.

IV. Rectifying Machines or Pulsating-Current Generators.—

17. These include: Open-coil arc machines, constant-current rectifiers, constant-potential rectifiers.

The losses in open-coil arc machines are essentially the same as in Sections 7 to 10 (closed-coil commutating machines). In this case, however, the load losses are usually greater, and the efficiency should be measured by input-and-output test, using wattmeters for measuring the output. In alternating - current rectifiers, the output must be also measured by wattmeter and not by voltmeter and ammeter, since owing to the pulsation of current and e.m.f., a considerable discrepancy may exist between watts and volt-amperes, amounting to as much as 10 or 15 per cent.

18. In constant-current rectifiers, transforming from constant-potential alternating to constant direct current, by means of constant-current transforming devices and rectifying commutators, the losses in the transformers are to be included in the efficiency, and have to be measured when operating the rectifier, since in this case the losses are generally greater than when feeding an alternating secondary circuit. In constant-current transforming devices, the load losses may be considerable, and, therefore, should not be neglected.

The most satisfactory method of determining the efficiency in rectifiers is to measure electric input and electric output by wattmeter. The input is usually inductive, owing to a considerable phase displacement and to wave distortion. For this reason the apparent efficiency should also be considered, since it is usually much lower than the true efficiency. The power consumed by the synchronous motor or other source driving the rectifier should be included in the electric input.

V. Stationary Induction Apparatus.—

19. Since the efficiency of induction apparatus depends upon the wave shape of e.m.f., it should be referred to a sine wave of e.m.f., except where expressly specified otherwise. The efficiency should be measured with

non-inductive load, and at rated frequency, except where expressly specified otherwise. The losses are:

a Molecular magnetic friction and eddy currents measured at open circuit and at rated voltage $- I r$, where I = rated current, r = resistance of primary circuit.

b. Resistance losses, the sum of the $I^2 r$ in the primary and in the secondary windings of a transformer, or in the two sections of the coil in a compensator or auto-transformer, where I = current in the coil or section of coil. r = resistance.

c. Load losses, *i. e.*, eddy currents in the iron and especially in the copper conductors, caused by the current. They should be measured by short-circuiting the secondary of the transformer and impressing upon the primary an e.m.f. sufficient to send full-load current through the transformer. The loss in the transformer under these conditions measured by wattmeter gives the load losses + $I^2 r$ losses in both primary and secondary coils.

d. Losses due to the methods of cooling, as power consumed by the blower in air-blast transformers, and power consumed by the motor driving pumps in oil or water cooled transformers. Where the same cooling apparatus supplies a number of transformers or is installed to supply future additions, allowance should be made therefor.

20. In potential regulators, the efficiency should be taken at the maximum voltage for which the apparatus is designed, and with non-inductive load, unless otherwise specified.

VI. Rotary Induction Apparatus.—

21. Owing to the existence of load losses, and since the magnetic density in the induction motor under load, changes in a complex manner, the efficiency should be determined by measuring the electric input by wattmeter, and the mechanical output at the pulley, gear, coupling, etc.

22. The efficiency should be determined at the rated frequency, and the input measured with sine waves of impressed e.m.f.

23. The efficiency may be calculated from the apparent input, the power factor, and the power output. The same applies to induction generators. Since phase displacement is inherent in induction machines, their apparent efficiency is also important.

24. In frequency converters, *i.e.*, apparatus transforming from an alternating system to an alternating system of different frequency, with or without a change in the number of phases, and in phase converters, *i. e.*, apparatus converting from an alternating system, usually single-phase, to another alternating system, usually polyphase, of the same frequency, the efficiency should also be determined by measuring both output and input.

VII. Transmission Lines.—

25. The efficiency of transmission lines should be measured with non-inductive load at the receiving end, with the rated receiving pressure and frequency, also with sinusoidal impressed e.m.f.'s, except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the ends of the line.

RISE OF TEMPERATURE.

General Principles.—

26. Under regular service conditions, the temperature of electrical machinery should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

27. The rise of temperature should be referred to the standard conditions of a room temperature of 25°C., a barometric pressure of 760 mm.

and normal conditions of ventilation; that is, the apparatus under test should neither be exposed to draught nor enclosed, except where expressly specified.

28. If the room temperature during the test differs from 25° C., the observed rise of temperature should be corrected by ½ per cent. for each degree C. Thus with a room temperature of 35° C., the observed rise of temperature has to be decreased by 5 per cent., and with a room temperature of 15° C., the observed rise of temperature has to be increased by 5 per cent. The thermometer indicating the room temperature should be screened from thermal radiation emitted by heated bodies, or from draughts of air. When it is impracticable to secure normal conditions of ventilation on account of an adjacent engine, or other sources of heat, the thermometer for measuring the air temperature should be placed so as fairly to indicate the temperature which the machine would have if it were idle, in order that the rise of temperature determined shall be that caused by the operation of the machine..

29. The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

In apparatus intended for intermittent service, as railway motors, starting rheostats, etc., the rise of temperature should be measured after operation under as nearly as possible the conditions of service for which the apparatus is intended, and the conditions of the test should be specified.

In apparatus which by the nature of their service may be exposed to overload, as railway converters; and in very high voltage circuits, a smaller rise of temperature should be specified than in apparatus not liable to overloads or in low voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

30. In electrical conductors, the rise of temperature should be determined by their increase of resistance where practicable. For this purpose the resistance may be measured either by galvanometer test, or by drop-of-potential method. A temperature coefficient of 0.42 per cent. per degree C., from and at 0° C., may be assumed for copper[1]. Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers.

When thermometers are applied to the free surface of a machine, it is desirable that the bulb of the thermometer should be covered by a pad of definite area. A convenient pad may be formed of cotton waste in a shallow circular box about one and a half inches in diameter, through a slot in the side of which the thermometer bulb is inserted. An unduly large pad over the thermometer tends to interfere with the natural liberation of heat from the surface to which the thermometer is applied.

31. With apparatus in which the insulating materials have special heat-resisting qualities, a higher temperature elevation is permissible.

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1. By the formula

$$R_t = R_0\,(1 + 0.0042\,t) \text{ and } R_{t+\theta} = R_0\,[1 + 0.0042\,(t + \theta)]$$

where R_t is the initial resistance at room temperature $t°$ C.

$R_{t+\theta}$ is the final resistance at temperature elevation $\theta°$ C.

R_0 is the inferred resistance at 0° C.

These combine into the formula

$$\theta = (238.1 + t)\left(\frac{R_{t+\theta}}{R_t} - 1\right) \qquad \text{degrees C.}$$

32. In apparatus intended for service in places of abnormally high temperature, a lower temperature elevation should be specified.

33. It is recommended that the following maximum values of temperature elevation should not be exceeded:

Commutating machines, rectifying machines and synchronous machines

Field and armature, by resistance, 50° C.

Commutator and collector rings and brushes, by thermometer, 55° C.

Bearings and other parts of machine, by thermometer, 40° C.

Rotary induction apparatus:

Electric circuits, 50° C., by resistance.

Bearings and other parts of the machine 40° C., by thermometer.

In squirrel-cage or short-circuited armatures, 55° C., by thermometer, may be allowed.

Transformers for continuous service—electric circuits by resistance 50° C., other parts by thermometer, 40° C., under conditions of normal ventilation.

Reactors, induction- and magneto-regulators—electric circuits by resistance 50° C., other parts by thermometer 40° C.

Where a thermometer, applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted. In using the thermometer, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

34. In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of full load, should not exceed 50° C., by resistance in electric circuits. In the case of transformers intended for intermittent service, or not operating continuously at full load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air-temperature should not exceed 50° C. by resistance in electric circuits and 40° C. by thermometer in other parts, after the period corresponding to the term of full load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the full-load test may be taken as three hours, unless otherwise specified. In the case of railway, crane and elevator motors, the conditions of service are necessarily so varied that no specific period corresponding to the full-load term can be stated.

35. The commercial rating of a railway motor should be the h.p. output giving 75° C. rise of temperature, above a room temperature of 25° C. after one hour's continuous run at 500 volts terminal pressure, on a stand, with the motor covers removed.

For determining the service temperature of a railway motor, the temperature rise should be determined by operating the motor on a straight and level track and under specified conditions:

(1). As to the load carried in tons per motor.
(2). The schedule speed in miles per hour.
(3). The number of stops per mile.
(4). The duration in seconds of the stops.
(5). The acceleration to be developed in miles per hour per second.
(6). The braking retardation to be developed in miles per hour per second.

These specifications should be determined, or agreed upon, as equivalent to the actual service, and the motors to be closed or open, according to the way in which they are to be operated in service.

The tests should be made in both directions over the same track.

By a " level track " should be understood a track in which the gradient does not exceed one-half per cent. at any point.

By a "straight track" should be understood a track in which the radius of curvature is nowhere less than the distance travelled by the car in 30 seconds, at the maximum speed reached during the run.

The wind velocity during a test should not exceed 10 miles per hour in any direction.

INSULATION.

36. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage.

Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

INSULATION RESISTANCE.—

37. Insulation resistance tests should, if possible, be made at the pressure for which the apparatus is designed.

The insulation resistance of the complete apparatus must be such that the rated voltage of the apparatus will not send more than $\frac{1}{1,000,000}$ of the full load current, at the rated terminal voltage, through the insulation. Where the value found in this way exceeds 1 megohm, 1 megohm is sufficient.

DIELECTRIC STRENGTH.—

38. The dielectric strength or resistance to rupture should be determined by a continued application of an alternating e.m.f. for one minute. The source of alternating e.m.f. should be a transformer of such size that the charging current of the apparatus as a condenser does not exceed 25 per cent. of the rated output of the transformer.

39. In alternating-current apparatus, the test should be made at the frequency for which the apparatus is designed.

40. The high-voltage tests should not be applied when the insulation is low, owing to dirt or moisture, and should be applied before the machine is put into commercial service.

The high potential test should be made at the temperature consumed under normal operation, as specified in Paragraph 2 under "Efficiency."

41. It should be pointed out that tests at high-voltages considerably in excess of the normal voltages, to determine whether specifications are fulfilled, are admissible on new machines only.

42. The test for dielectric strength should be made with the completely assembled apparatus and not with its individual parts, and the voltage should be applied as follows:[1]

1st. Between electric circuits and surrounding conducting material, and

2d. Between adjacent electric circuits, where such exist, as in transformers.

The tests should be made with a sine wave of e.m.f., or where this is not available, at a voltage giving the same striking distance between needle points in air, as a sine wave of the specified e.m.f., except where expressly specified otherwise. As needles, new sewing needles should be used. It is recommended to shunt the apparatus during the test by spark gap of needle points set for a voltage exceeding the required voltage by 10 per cent.

A table of approximate sparking distances is given in Appendix V.

43. The following voltages are recommended for apparatus not including transmission lines or switchboards:

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1. [NOTE,—This Section (No. 42), was referred back by the Convention to the Committee with power to amend, and may be subsequently revised.—EDITOR.

Rated Terminal Voltage.	Rated Output.	Testing Voltage.
Not exceeding 400 volts	Under 10 k.w.	1,000 volts.
" " "	10 k.w. and over	1,500 "
400 and over, but less than 800 volts	Under 10 k.w.	1,500 "
" " " "	10 k.w. and over	2,000 "
800 " " 1,200 "	Any	3,500 "
1,200 " " 2,500 "	Any	5,000 "
2,500 " " 10,000 "	Any	Double the normal rated voltages.
10,000 " " 20,000 "	Any	10,000 volts above normal rated voltages.
20,000 "	Any	50 % above normal rated voltages.

Except that transformers of 5,000 volts or less, directly feeding consumption circuits, should be tested at 10,000 volts.

Synchronous motor fields and fields of converters started from the alternating current side .... 5,000 volts.

Alternator field circuits should be tested under a break-down test voltage corresponding to the rated voltage of the exciter, and referred to an output equal to the output of the alternator; *i. e.*, the exciter should be rated for this test as having an output equal to that of the machine it excites.

Condensers should be tested at twice their rated voltage and at their rated frequency.

The values in the table above are effective values, or square roots of mean square, reduced to a sine wave of e.m.f.

44. In testing insulation between different electric circuits, as between primary and secondary of transformers, the testing voltage must be chosen corresponding to the high-voltage circuit.

45. In transformers of 20,000 volts upwards, it should be sufficient to test the transformer by operating it at 50 per cent. above its rated voltage; if necessary, with sufficiently higher frequency to induce this voltage.

46. The test of the insulation of a transformer, if no testing transformer is available, may be made by connecting one terminal of the high-voltage winding to the core and low-voltage winding, and then repeating the test with the other terminal of the high-voltage winding so connected. The test of dielectric resistance between the low voltage winding and the core should be in accordance with the recommendation in Section 43, for similar voltages and capacities.

47. High voltage tests on transformers or other apparatus should be based upon the voltages between the conductors of the circuit to which they are connected.

48. When machines or apparatus are to be operated in series, so as to employ the sum of their separate e.m.f.'s, the voltage should be referred to this sum, except where the frames of the machines are separately insulated both from ground and from each other.

The insulation between machines and between each machine and ground should be tested, the former referred to the voltage of one machine, and the latter to the total voltage of the series.

49. Underground cables, and line switches, should be tested by the application of an alternating e.m.f. for one minute at twice the voltage at which the cable or switch is to be operated.

REGULATION.

50. The term regulation should have the same meaning as the term "inherent regulation," at present frequently used.

51. The regulation of an apparatus intended for the generation of constant potential, constant current, constant speed, etc., is to be measured by the maximum variation of potential, current, speed, etc., occurring within the range from full-load to no-load, under such constant conditions

of operation as give the required full-load values, the condition of full-load being considered in all cases as the normal condition of operation.

52. The regulation of an apparatus intended for the generation of a potential current, speed, etc., varying in a définite manner between full load and no load, is to be measured by the maximum variation of potential current, speed, etc., from the satisfied condition, under such constant conditions of operation as give the required full-load values.

If the manner in which the variation in potential, current, speed, etc., between full-load and no-load is not specified, it should be assumed to be a simple linear relation; *i. e.*, undergoing uniform variation between full load and no-load.

The regulation of an apparatus may, therefore, differ according to its qualification for use. Thus, the regulation of a compound-wound generator specified as a constant-potential generator, will be different from that it possesses when specified as an over-compounded generator.

53. The regulation is given in percentage of the full-load value of potential, current, speed, etc., and the apparatus should be steadily operated during the test under the same conditions as at full load.

54. The regulation of generators is to be determined at constant speed, of alternating apparatus at constant impressed frequency.

55. The regulation of a generator-unit, consisting of a generator united with a prime-mover, should be determined at constant conditions of the prime mover; *i. e.*, constant steam pressure, head, etc. It would include the inherent speed variations of the prime-mover. For this reason the regulation of a generator-unit is to be distinguished from the regulation of either the prime-mover, or of the generator contained in it, when taken separately.

56. In apparatus generating, transforming or transmitting alternating currents, regulation should be understood to refer to non-inductive load, that is to a load in which the current is in phase with the e.m.f. at the output side of the apparatus, except where expressly specified otherwise.

57. In alternating apparatus receiving electric power, regulation should refer to a sine wave of e.m.f., except where expressly specified otherwise.

58. In commutating machines, rectifying machines and synchronous machines, as direct-current generators and motors, alternating-current and polyphase generators, the regulation is to be determined under the following conditions:

a. At constant excitation in separately excited fields.
b. With constant resistance in shunt field circuits, and
c. With constant resistance shunting series fields; *i. e.*, the field adjustment should remain constant, and should be so chosen as to give the required full-load voltage at full-load current.

59. In constant-potential machines, the regulation is the ratio of the maximum difference of terminal voltage from the rated full-load value (occurring within the range from full load to open circuit) to the full-load terminal voltage.

60. In constant-current apparatus, the regulation is the ratio of the maximum difference of current from the rated full-load value (occurring within the range from full-load to short-circuit, or minimum limit of operation), to the full-load current, at constant speed; or, in transformers, etc., at constant impressed voltage and frequency.

61. In constant-power apparatus, the regulation is the ratio of maximum difference of power from the rated full-load value (occurring within the range of operation specified) to the rated power.

62. In over-compounded machines, the regulation is the ratio of the maximum difference in voltage from a straight line connecting the no-load and full-load values of terminal voltage as function of the current, to the full-load terminal voltage.

63. In constant-speed continuous-current motors, the regulation is the

ratio of the maximum variation of speed from its full-load value (occurring within the range from full-load to no-load) to the full-load speed.

64. In constant-potential non-inductive transformers, the regulation is the ratio of the rise of secondary terminal voltage from full-load to no-load (at constant primary impressed terminal voltage) to the secondary terminal voltage.

65. In induction motors, the regulation is the ratio of the rise of speed from full-load to no-load (at constant impressed voltage), to the full-load speed.

The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism, to the synchronous speed.

66. In converters, dynamotors, motor-generators and frequency-converters, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated full-load voltage (at constant impressed voltage and at constant frequency), to the full-load voltage on the output side.

67. In transmission lines, feeders, etc., the regulation is the ratio of maximum voltage difference at the receiving end, between no-load and full non-inductive load, to the full-load voltage at the receiving end, with constant voltage impressed upon the sending end.

68. In steam engines, the regulation is the ratio of the maximum variation of speed in passing from full-load to no-load (at constant steam pressure at the throttle) to the full-load speed.

69. In a turbine or other water-motor, the regulation is the ratio of the maximum variation of speed from full-load to no-load (at constant head of water; *i. e.*, at constant difference of level between tail race and head race), to the full-load speed.

70. In alternating-current apparatus, in addition to the non-inductive regulation, the impedance ratio of the apparatus should be specified; *i. e.*, the ratio of the voltage consumed by the total internal impedance of the apparatus at full-load current, to its rated full-load voltage. As far as possible, a sinusoidal current should be used.

71. When in synchronous machines the regulation is computed from the terminal voltage and impedance voltage, the exciting ampere-turns corresponding to terminal voltage plus armature-resistance-drop, and the ampere-turns at short-circuit corresponding to the armature-impedance-drop, should be combined vectorially to obtain the resultant ampere-turns, and the corresponding internal e.m.f. should be taken from the saturation curve.[1]

VARIATION AND PULSATION —

72. In prime movers which do not give an absolutely uniform rate of rotation or speed, as in steam engines, the "variation" is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution as 360°; and the pulsation is the ratio of the maximum change of speed in an engine cycle to the average speed.

73. In alternators or alternating-current circuits in general, the variation is the maximum difference in phase of the generated wave of e.m.f. from a wave of absolutely constant frequency, expressed in degrees, and is due to the variation of the prime mover. The pulsation is the ratio of the maximum change of frequency during an engine cycle to the average frequency.

74. If n = number of poles, the variations of an alternator is $n/2$ times the variation of its prime-mover if direct connected, and $n/2p$ times the variation of the prime-mover if rigidly connected thereto in the velocity ratio p.

1 [NOTE —This Section (No 71), was referred back by the Convention to the Committee with power to amend, and may be subsequently revised.—EDITOR.

RATING.

75. Both electrical and mechanical power should be expressed in kilowatts, except when otherwise specified. Alternating-current apparatus should be rated in kilowatts on the basis of non-inductive condition; *i. e.*, with the current in phase with the terminal voltage.

76. Thus the electric power generated by an alternating-current apparatus equals its rating only at non-inductive load, that is, when the current is in phase with the terminal voltage.

77. Apparent power should be expressed in kilovolt-amperes as distinguished from real power in kilowatts.

78. If a power-factor other than 100 per cent. is specified, the rating should be expressed in kilovolt-amperes and power-factor, at full load.

79. The full-load current of an electric generator is that current which with the rated full-load terminal voltage gives the rated kilowatts, but in alternating-current apparatus only at non-inductive load.

80. Thus, in machines in which the full-load voltage differs from the no-load voltage, the full-load current should refer to the former.

If P = rating of an electric generator and E = full-load terminal voltage, the full load current is:

$I = \frac{P}{E}$ in a continuous-current machine or single-phase alternator.

$I = \frac{P}{E\sqrt{3}}$ in a three-phase alternator.

$I = \frac{P}{2E}$ in a quarter-phase alternator.

81. Constant-current machines, such as series arc-light generators, should be rated in kilowatts based on terminal volts and amperes at full load.

82. The rating of a fuse or circuit breaker should be the current-strength which it will continually carry. In addition thereto, the current strength at which it will open the circuit should be specified.

CLASSIFICATION OF VOLTAGES AND FREQUENCIES.—

83. In direct-current, low-voltage generators, the following average terminal voltages are in general use and are recommended:

125 volts. 250 volts. 550 to 600 volts.

84. In direct-current and alternating-current low-voltage circuits, the following average terminal voltages are in general use and are recommended:

110 volts. 220 volts.

In direct-current power circuits, for railway and other service, 500 volts may be considered as standard.

85. In alternating-current, constant-potential, primary-distribution circuits, an average e.m.f. of 2,200 volts, with step-down transformers of ratios 1/10 and 1/20, is in general use, and is recommended.

86. In alternating-current, constant-potential, high-pressure circuits, at the receiving end, the following voltages are in general use, and are recommended:

6,000. 10,000. 15,000. 20,000. 30,000. 40,000. 60,000.

87. In alternating-current generators, or generating systems, a range of terminal voltage should be provided from no-load voltage to 10 per cent. in excess thereof, to cover drop in transmission. If a greater range than ten per cent. is specified, the generator should be considered as special.

88. In alternating-current circuits, the following approximate frequencies are recommended as desirable:

25 ~ 60 ~ 120 ~ (1)

These frequencies are already in extensive use and it is deemed advisable to adhere to them as closely as possible.

OVERLOAD CAPACITIES.—

89. All guarantees on heating, regulation, sparking, etc., should apply to the rated load, except where expressly specified otherwise, and in alternating-current apparatus to the current in phase with the terminal e.m.f., except where a phase displacement is inherent in the apparatus.

90. All apparatus should be able to carry the overload specified in Section 92, without self-destruction by heating, sparking, mechanical weakness, etc., and with an increase in temperature elevation not exceeding 15° C., above those specified for full loads, the overload being applied after the apparatus has acquired the temperature corresponding to full-load continuous operation. (See Sections 30 to 34.)

91. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

92. The following overload capacities are recommended:

1st. In direct-current generators and alternating-current generators; 25 per cent. for two hours.

2d. In direct-current motors, induction motors and synchronous motors, not including railway motors and other apparatus intended for intermittent service, 25 per cent. for two hours, and 50 per cent. for one minute, for momentary overload capacity.

3d. Synchronous converters. 50 per cent. for one-half hour.

4th. Transformers. 25 per cent. for two hours. Except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

5th. Exciters of alternators and other synchronous machines, 10 per cent. more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time.

7th. All exciters of alternating-current, single-phase or polyphase generators should be able to give at constant speed, sufficient voltage to excite the alternator, at the rated speed, to the full load terminal voltage, at the rated output in kilovolt-amperes and with 50 per cent, power factor.

LUMINOUS SOURCES.—

93. It is customary in industrial practice at the present time to rate incandescent lamps upon the basis of their mean horizontal candle-power; but in comparing sources of light in which the relative distribution of luminosity differs considerably, the comparison should be based upon the total quantity of light, or total flux of light emitted by each source.

94. The mean spherical intensity of a luminous source is its total flux of light, expressed in lumens, divided by 4π. If the mean spherical intensity be expressed in British candles, the flux of light will be in British-candle-lumens (B. C. Lumens). If the mean spherical intensity be expressed in Hefners, the flux of light will be expressed in Hefner-lumens (H. Lumens).

95. The efficiency of a luminous source should be defined as the ratio of the light it emits to the power it consumes. In the case of an incandescent lamp, this ratio might be expressed in B. C. Lumens per watt at lamp terminals.

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1. The frequency of 120~ may be considered as covering the already existing commercial frequencies between 120~ and 140~.

96. The specific consumption of a lamp should be the reciprocal of its efficiency, or the watts per B. C. Lumen.

97. The consumption per horizontal candlepower of a lamp is the ratio of power consumed at terminals to the mean horizontal candlepower, or watts per mean horizontal candlepower.

98. The Hefner-Alteneck amyl-acetate lamp is, in spite of its unsuitable color, the standard luminous source generally used in accurate photometric measurements. In comparing lamps with this standard, the ratio of the horizontal intensities of the Hefner and British candles may be accepted conventionally as follows: 1 Hefner under Reichsanstalt standard conditions = 0.88 British candle

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APPENDIX I.

Efficiency of Phase-Displacing Apparatus.—

In apparatus producing phase displacement as, for example, synchronous compensators, exciters of induction generators, reactors, condensers, polarization cells, etc., the efficiency should be understood to be the ratio of the volt-ampere activity to the volt-ampere activity plus power loss.

The efficiency may be calculated by determining the losses individually, adding to them the volt-ampere activity, and then dividing the volt-ampere activity by the sum.

1st. In synchronous compensators and exciters of induction generators, the determination of losses is the same as in other synchronous machines under Sections 11 and 12.

2d. In reactive coils the losses are molecular friction, eddy losses and I^2r loss. They should be measured by wattmeter. The efficiency of reactive coils should be determined with a sine wave of impressed e.m.f., except where expressly specified otherwise. In reactive coils, the load losses may be considerable.

3d. In condensers, the losses are due to dielectric hysteresis and leakage, and should be determined by wattmeter with a sine wave of e.m.f

4th In polarization cells, the losses are those due to electric resistivity and a loss in the electrolyte of the nature of chemical hysteresis and are usually very considerable. They depend upon the frequency, voltage and temperature, and should be determined with a sine wave of impressed e.m.f., except where expressly specified otherwise.

APPENDIX II.

Apparent Efficiency.—

In apparatus in which a phase displacement is inherent to their operation, apparent efficiency should be understood as the ratio of net power output to volt-ampere input.

Such apparatus comprise induction motors, reactive synchronous converters, synchronous converters controlling the voltage of an alternating current system, self-exciting synchronous motors, potential regulators and open magnetic circuit transformers, etc.

Since the apparent efficiency of apparatus generating electric power depends upon the power factor of the load, the apparent efficiency, unless otherwise specified, should be referred to a load power-factor of unity.

APPENDIX III.

Power Factor and Inductance Factor.—

The power factor in alternating circuits or apparatus may be defined as the ratio of the electric power, in watts, to volt-amperes.

The inductance factor is to be considered as the ratio of wattless volt-amperes to total volt amperes.

Thus, if p = power factor, q = inductance factor. then with a sine wave of e.m.f.

$$p^2 = q^2 = 1$$

The power factor is the

$$\frac{\text{(energy component of current or e.m.f.)}}{\text{(total current or e.m.f.)}} = \frac{\text{true power}}{\text{volt amperes}}$$

and the inductance factor is the

$$\frac{\text{(wattless component of current or e.m.f.)}}{\text{(total current or e.m.f.)}}$$

Since the power-factor of apparatus supplying electric power depends upon the power-factor of the load, the power-factor of the load should be considered as unity, unless otherwise specified.

APPENDIX IV.

The following notation is recommended:

E, e, voltage, e.m.f., potential difference
I, i, current
P, power
φ, magnetic flux
$\mathcal{B}$, magnetic density
R, r, resistance
x, reactance
Z, z. impedance
L, l, inductance
C, c, capacity
Y, y, admittance
b, susceptance
g, conductance.

Vector quantities when used should be denoted by capital italics

APPENDIX V.

Table of Sparking Distances in Air between Opposed Sharp Needle-Points, for Various Effective Sinusoidal Voltages, in inches and in centimetres.

Kilovolts Sq. Root of Mean Square	Distance. Inches	Distance. Cms.	Kilovolts Sq. Root of Mean Square	Distance. Inches	Distance. Cms.
5	0.225	0.57	60	4.65	11.8
10	0.47	1.19	70	5.85	14.9
15	0.725	1.84	80	7.1	18.0
20	1.0	2.54	90	8.35	21.2
25	1.3	3.3	100	9.6	24.4
30	1.625	4.1	110	10.75	27.3
35	2.0	5.1	120	11.85	30.1
40	2.45	6.2	130	12.95	32.9
45	2.95	7.5	140	13.95	35.4
50	3.55	9.0	150	15.0	38.1

Discussion.

President Steinmetz:—Gentlemen, as you know, the Committee on Standardization has been working very hard for about two years in amending and adding to this report. It has been submitted to a number of prominent engineers to obtain their opinions, has been reconsidered and finally submitted to the Board of Directors, and by them ordered to be printed and submitted for final action by this Annual Convention. It is left to you, then, to say what action you care to take. Discussion on the report is now in order.

[The report was discussed by Prof. Owens, President Steinmetz, Dr. Kennelly, Prof. Adams, Mr. Lieb, Dr. Matthews, Dr. Nichols, Mr. Rice, Prof. Thomson and Mr. Hering.]

Dr. Perrine:—I think our committee has worked very faithfully and presented a very able report, and I therefore move that the report be received and adopted.

President Steinmetz:—I should like to make the amendment that the report be adopted as a whole and that Sections 71 and 42, the two paragraphs regarding which serious objections have been raised, should be referred back to the Committee on Standardization, with power to amend if they see fit.

Mr. Stanley:—I heartily endorse the suggestion made by Mr. Lieb regarding a definition of what constitutes a proper and satisfactory meter. It does not seem to me that that question ought to be left to irresponsible people to decide; it ought to be taken up by men who are competent to carefully analyze the subject, and a proper and careful report made on it. It reminds me of the definition which I heard the late Mr. Franklin Pope made of electric machinery—there were just two kinds, ours and the other fellows'; and I think that is about the status of the meter subject to-day. There are so many minor points to be considered in answering the question of what constitutes a good meter, that it really takes considerable time and study to place the subject clearly before one's self, and I hope that this Committee will give it thought and consult authorities on the subject before they finally make a report.

The amendment was accepted and the motion was then carried.

By permission of President Steinmetz, Prof. Robert B. Owens was given the floor to extend in behalf of McGill University an invitation to hold the next Annual Convention in Montreal. Prof. Owens added that it was proposed, also, to invite the Institution of Electrical Engineers to hold its meeting there at the same time, and make it a joint convention. After remarks by President Steinmetz, Prof. Thomson, Mr. Hering, Mr. Mailloux and Mr. Sachs, the invitation was upon motion of Mr. Rice referred to the Committee on Papers.

A paper on the "Determination of Alternator Characteristics" by Prof. L. A. Herdt was then read by Prof. Owens.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 20th. 1902.

THE DETERMINATION OF ALTERNATOR CHARACTERISTICS.

BY LOUIS A. HERDT.

The exacting requirements now to be met in regard to the performance of A. C. machinery and the expense of duplicating in the testing room all the conditions of future operations,make proper indirect methods for the determination of the characteristics of A. C. apparatus of great value.

In the following discussion, the e.m.f. induction and current relations under different conditions as to load and power factor in the armatures of several types of A. C. generators will be considered both theoretically and experimentally, and indirect methods for obtaining the regulation of a particular machine developed and applied to those of other types.

For convenience of reference the following divisions have been made:

Armature reaction and armature reactance.

Tests of an inductor alternator.

Alternator regulation, indirect methods for determination.

Application to inductor machine.

Application to other types.

Armature Reaction and Armature Reactance.

Consider the no-load induction distribution on an alternator of the type shown in Fig. 1, structural details of which are given in Fig. 5. During the rotation of the inductor the armature induction pulsates between a maximum and minimum value, but is constant in direction. When an inductor lug is exactly

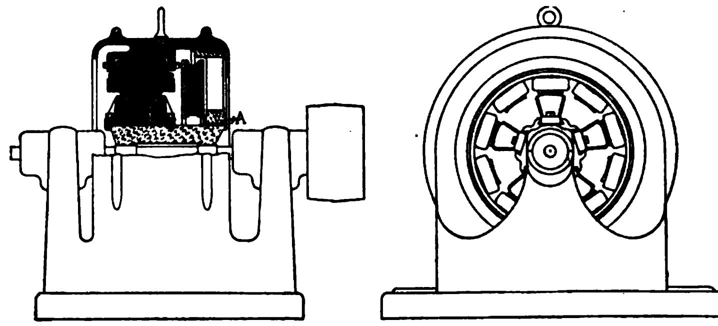

FIG 1.

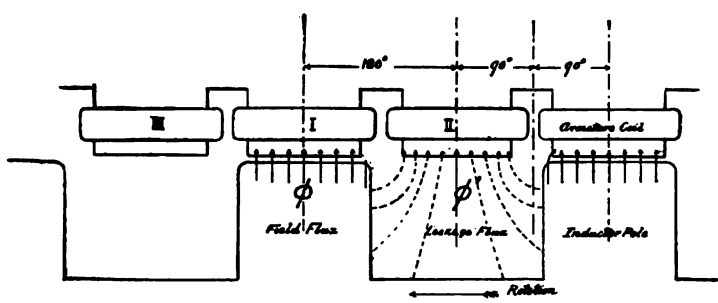

FIG. 2.

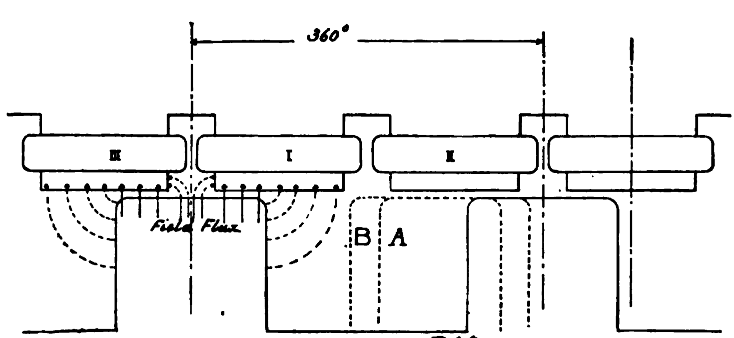

FIG 3.

opposite an armature coil (see Fig. 2), the induction through that coil is a maximum, but as the lug recedes from it, the induction diminishes to a minimum, until the lug stands opposite the adjacent coil. The minimum induction is a leakage flux and the e.m.f. of the machine is diminished in proportion to the ratio of this minimum induction to its maximum value. This leakage flux should, therefore, be as small as possible.

The average e.m.f. induced in any armature coil is the difference between the flux φ, shown in Fig. 2, which passes through that coil when covered by an inductor lug, and the flux φ', when

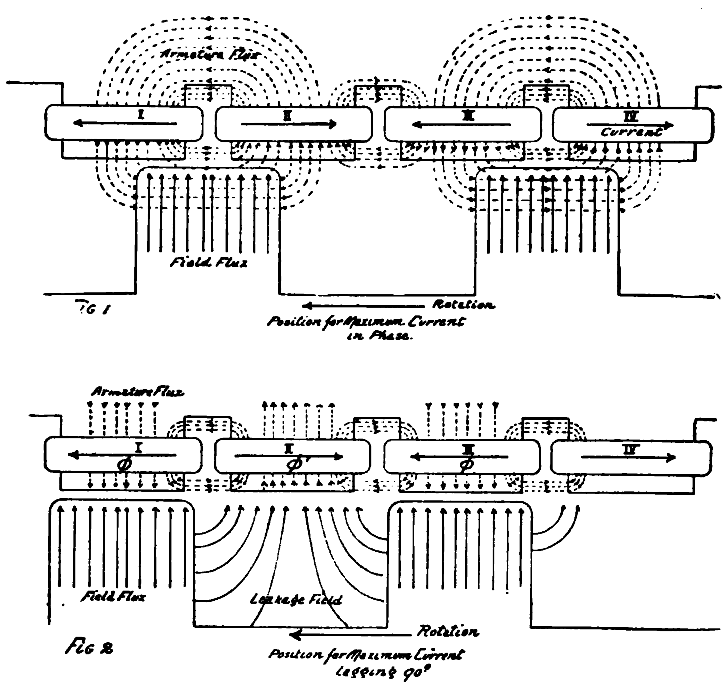

FIG. 4.

the coil is midway between these two adjacent lugs, divided by the time of half a period, that is:

$$\underset{\text{average}}{\varepsilon} = (\varphi - \varphi') \div (T/2)$$

Fig. 3 will be referred to later.

When the armature carries a current, the effective magnetic flux is the resultant of the m.m.f. of the field and of the armature ampere turns. If the armature current lags by 90° the field and armature m.m.f.'s will exactly oppose each other, as shown in Diagram 2, Fig. 4.

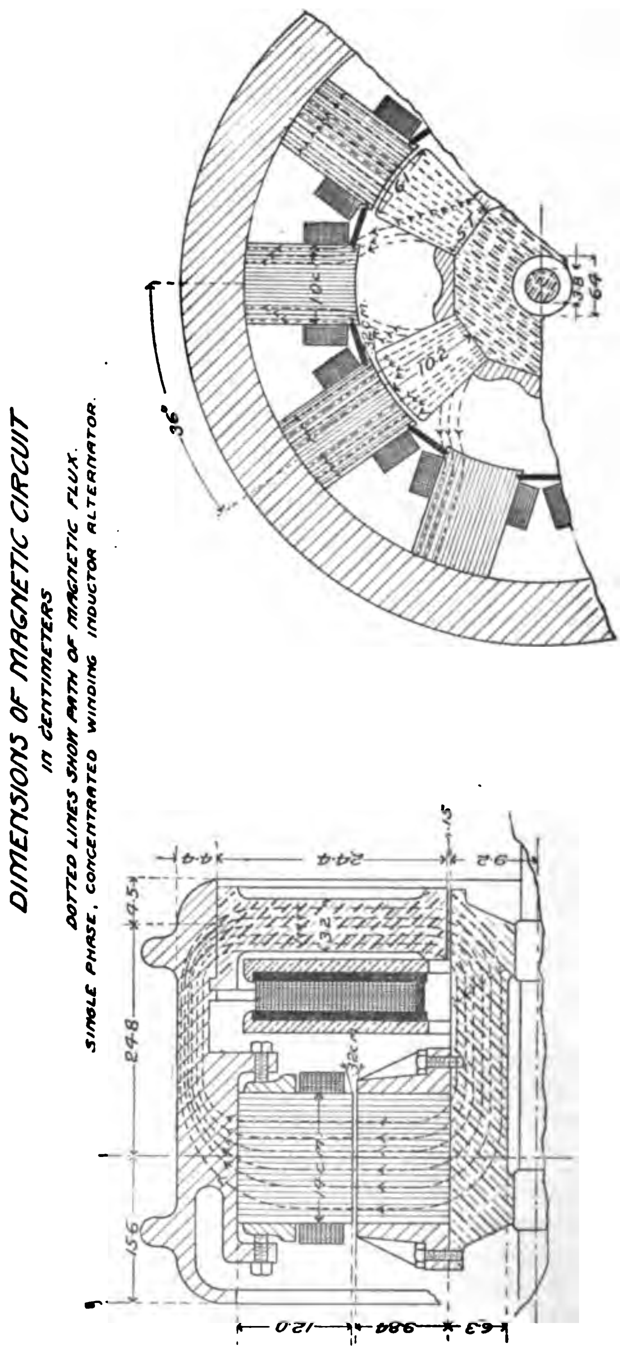
DIMENSIONS OF MAGNETIC CIRCUIT
IN CENTIMETERS
DOTTED LINES SHOW PATH OF MAGNETIC FLUX.
SINGLE PHASE, CONCENTRATED WINDING INDUCTOR ALTERNATOR.
36°

Fig. 5.

If n and i are respectively the number of turns and amperes in field coils, and N and I the number of turns and the effective current in one armature coil, the resultant m.m.f. of field and armature will be:

$$(n\,i - N\,I\,\sqrt{2}) \text{ for coil 1.}$$

and

$$(n\,i + N\,I\,\sqrt{2}) \text{ for coil 2.}$$

As seen, the m.m.f.'s of coils 1 and 3 directly oppose the field m.m.f., diminish the maximum induction, while the action of coil 2 is to increase the leakage flux.

Both of these actions diminish the induced e.m.f. The reluctance of the path of the coils is, however, very different; the magnetic circuit of coil 1 is that of the machine, and varies with the saturation of the machine circuit, while the magnetic circuit of coil 2 is made up largely of air, and the flux through it is proportional to the armature current.

The m.m.f. due to this quadrature current, in addition to diminishing the effective armature flux, will generate lines of force encircling the armature coils, but not passing through the main magnetic circuit of the machine. This cross-magnetizing effect is, however, small in the concentrated winding type of alternator with quadrature current.

With in-phase current the case, however, is different. The diminution of effective flux (see position of inductor lug, Fig. 3), unless the machine is highly saturated, is negligible, for the m.m.f. of coils 1, and 2 (see Diagram 1, Fig. 4) tends only to set up a cross flux increasing the induction of the leading tip of the inductor lug and diminishing the induction through the trailing tip, producing a change in the distribution of magnetic flux and resultant wave form, but altering little the resultant induction or total e.m.f. generated. It is thus seen that the effect of the armature current in diminishing the total effective induction and varying its distribution depends on the phase relation of e.m.f. and current.

In considering the path presented to the armature flux at any angular position of the coils relatively to the inductor lugs, other than the particular ones just given, it will be seen that its reluctance periodically changes. As before stated, with the inductor lug opposite an armature coil (position A, Fig. 3), the reluctance of the magnetic of the armature coils is that of the machine, but after a small angular displacement of the inductor (position B,

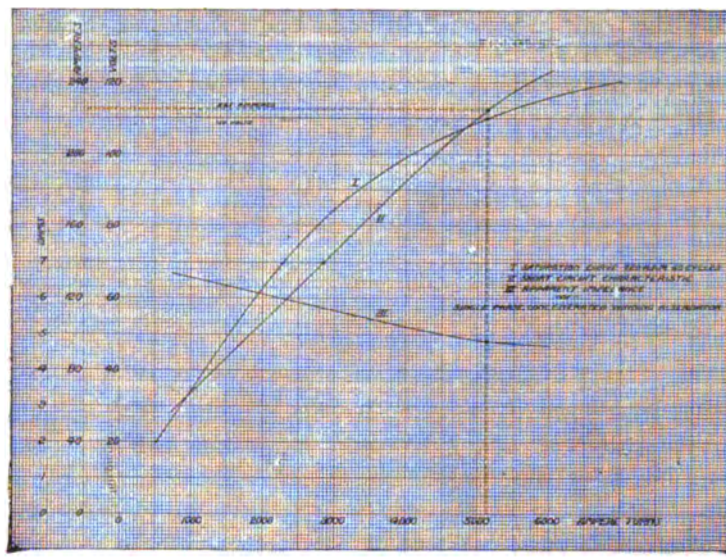

FIG. 6.

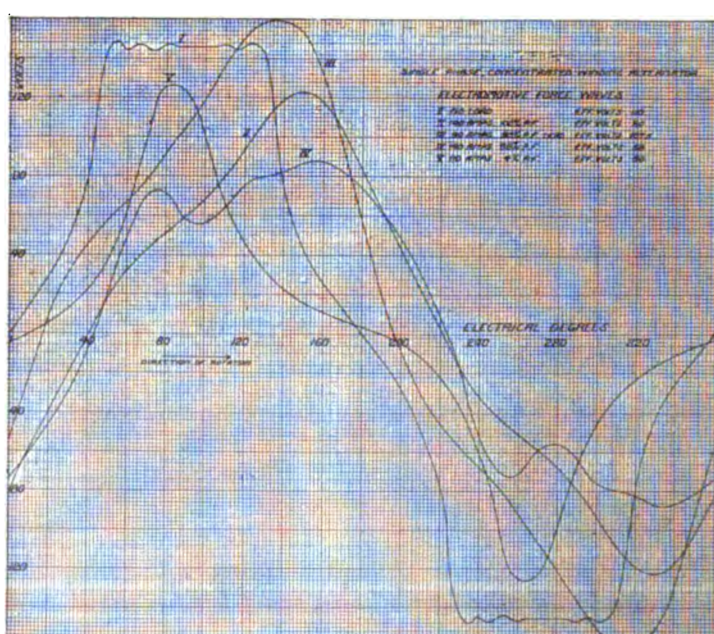

FIG. 7.

Fig. 3), the reluctance is diminished, the flux due to armature current increasing and becoming a purely local one. This periodic fluctuation of the reluctance in the path of the induction set up by the armature m.m.f., as easily seen, may have a very marked effect on the regulation and wave form of machines of the type illustrated.

TEST OF AN INDUCTOR ALTERNATOR.

The machine is that illustrated in Fig. 1. The magnetic dimensions are given in Fig. 5. The armature consists of ten coils of 75 turns each, connected in parallel, the resistance cold equals .04 ohms. The excitation is effected by a single exciting coil, as seen, containing 1,710 turns. The normal output is 15.4 k.w.; voltage, 110; speed, 720 r.p.m.

The following tests were made:

Saturation curve, 60 cycles.

Short-circuit characteristic, 60 cycles.

Real induced e.m.f. waves, with different armature currents and different power factors, 3 amperes field excitation.

Current waves under different conditions.

Curves showing variation of induction due to armature current, for different positions of the inductor lug, 3 amperes field excitation.

From these were deduced curves of synchronous impedance, curves of induction distribution under different conditions of load, and curves, which for the present, we will call counter e.m.f. waves. Curve I, Fig. 6, is the saturation curve. Curve II is the short-circuit characteristic. Curve III is the synchronous impedance, calculated. Curve 1, Fig. 7, is the no-load or nominal induced e.m.f. wave. Curve II is the real induced e.m.f. wave for in-phase current of 140 amperes .The great variation in the induction distribution with the resultant change of wave form will be noticed. Curve III, Fig. 7, is the real induced e.m.f. wave for a leading current of 90 amperes, 95% power factor. Owing to the fact that with this particular power factor the armature current (Curve III, Fig. 8) is in step with the nominal induced e.m.f., the total effective induction has been but slightly altered in amount, as seen by Curve II, Fig. 9; its distribution, however, has been changed.

Curve IV, Fig. 7, is the real induced e.m.f. wave for 140 amperes, 88% power factor, lagging, and clearly shows the effect of diminishing power factor in bringing the real induced e.m.f. wave back in phase with the nominal induced e.m.f.

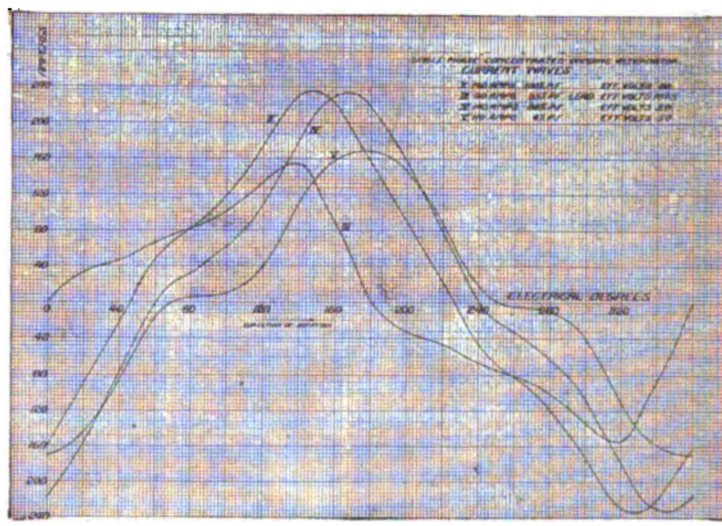
CURRENT WAVES
ELECTRICAL DEGREES

Fig. 8.

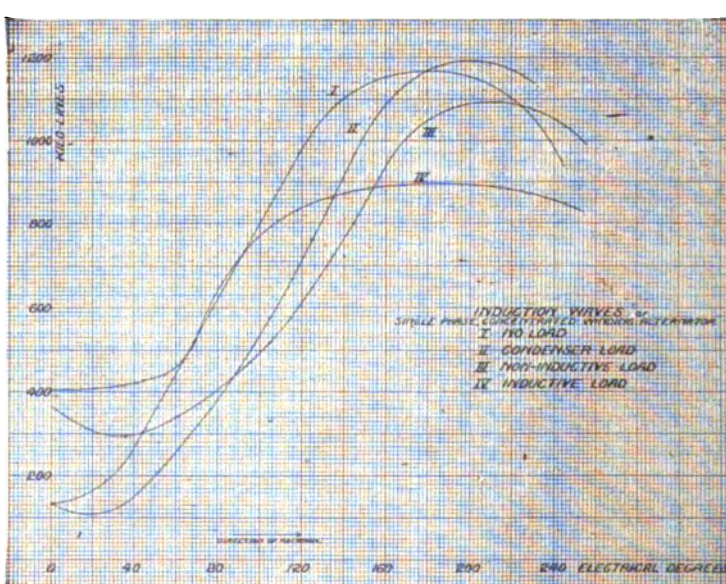
FIELD LINES
1200
1000
800
600
400
200
0
40
80
120
160
200
240 ELECTRICAL DEGREES
INDUCTION WAVES of
SINGLE PHASE, CONCENTRATED WINDING ALTERNATOR
I NO LOAD
II CONDENSER LOAD
III NON-INDUCTIVE LOAD
IV INDUCTIVE LOAD

Fig. 9.

Curve V is the real induced e.m.f. wave for 110 amperes, 4% power factor, lagging. Here the e.m.f. wave, while greatly altered in extent and form, has returned almost exactly to, and in phase relation with, the nominal induced e.m.f., as, of course, would be expected. All the above e.m.f. waves were taken with a constant field excitation of three amperes and a speed of 720 r.p.m.

Curves II, III, IV and V, or curves of real induced e.m.f. waves under different conditions, were taken from a test coil of 75 turns, wrapped uniformly about an armature coil, and they equal the machine terminal e.m.f. waves plus the armature ohmic drop. For e.m.f. wave measurements a special contact maker was used, charging and discharging a condenser through a Weston voltmeter.

The tremendous change of wave form with character of load in this machine, will be noted to be far too much for successful commercial use, but for purposes of illustration the machine is an excellent one.

Curves II, III, IV and V, Fig. 8, are current waves corresponding to the e.m.f. waves II, III, IV and V, Fig. 7. The shift of current with the nature of load shows clearly the change of the armature m.m.f. from a cross-magnetizing to a demagnetizing effect, as the lag increases from zero to 90°.

Curves I, II, III, and IV, Fig. 9, show the variation of induction through one armature coil with different positions of inductor lug, for armature currents (Fig. 8) of zero amperes, 90 amperes, 95% power factor, leading; 140 amperes, 100 % power factor; and 110 amperes, 4% power factor, lagging. These curves were determined by integrating the areas of the real induced e.m.f. waves, Curves I, II, III and V, Fig. 7.

By Curve I it will be noticed that the maximum induction in one armature coil is slightly over 1,160,000 lines, representing a maximum induction per square centimetre of about 10,000 lines. The minimum induction, or leakage flux, occurring when the armature coil is midway between two adjacent inductor lugs, is 130,000 lines.

Curve II is the induction wave with 90 amperes armature current, 95% power factor, leading. This current, as before stated, being in step with the nominal induced e.m.f., the maximum and minimum values of the induction through any of the armature coils is but slightly altered by the armature current, but the shift of the induction wave, due to the cross-magnetizing effect of the armature m.m.f., is easily seen.

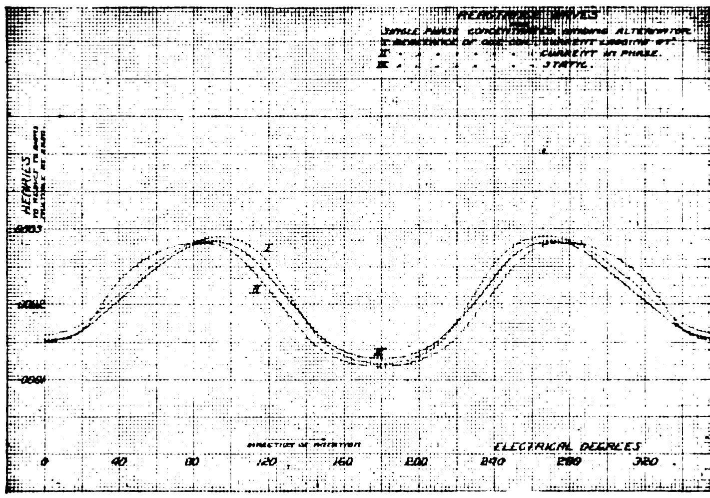
HENRIES
ELECTRICAL DEGREES
0
40
80
120
160
200
240
280
320

Fig. 10.

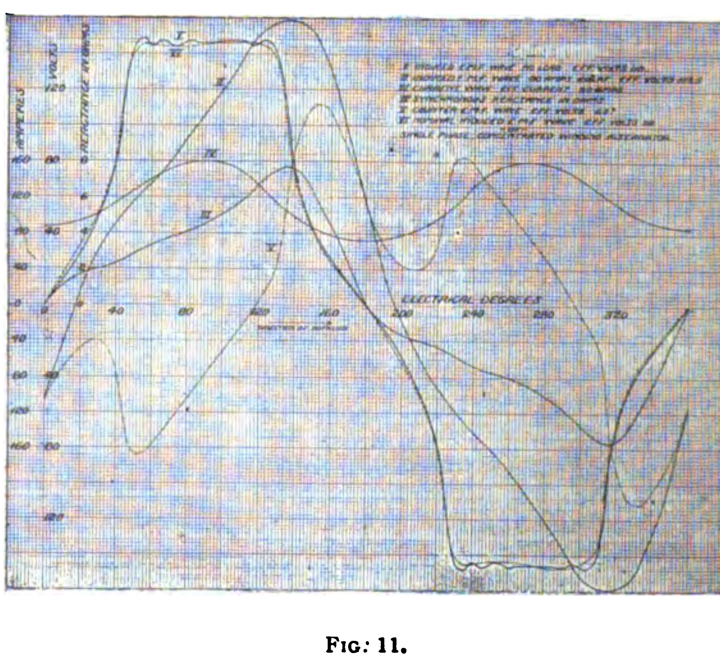
ELECTRICAL DEGREES

Fig. 11.

Curve III is the induction wave corresponding to a current of 140 amperes in step with the terminal voltage, but lagging behind the nominal induced e.m.f. by nearly 50°, due to the armature reactance. The demagnetizing effect of the armature current now becomes marked, the maximum induction being diminished and the leakage flux increased.

Curve IV is the induction wave for 110 amperes, lagging 85° behind the nominal induced e.m.f. This curve shows with great clearness the demagnetizing effect of wattless armature currents, and the virtual absence of any cross-magnetizing effect. The maximum no-load induction is reduced from 1,160,000 lines to approximately 900,000 lines, and the no-load leakage is increased from 130,000 to 400,000 lines.

The shape of the induction wave is altered, becoming flatter, and its maximum and minimum values are changed, but it has regained a practically in-phase angular relation to the no-load induction wave. The diminution of voltage with quadrature current is thus seen to be due almost entirely to armature reaction.

From the above induction waves and from the instantaneous values of armature current, given in Fig. 8, the total induction due to the armature m.m.f. diminution of field flux, increase of stray field and cross lines for different positions of the inductor, are readily found.

If π is the increase or decrease of induction through the coil for any position of the inductor above or below the induction when no armature current is flowing, and if π be divided by the instantaneous value of the current and by 10^8, the result will be the total inductance of the coil in henrys, and multiplying by the angular velocity and the number of turns in the armature coil, we have the instantaneous value of the total inductance of the coil in ohms. This includes both the effective armature reaction and armature reactance. In Fig. 10 are given Curves I and II of total armature reactance calculated as above. Curve I is for non-inductive external load. Curve II is for current in phase with the nominal induced e.m.f.

These curves of inductance or reactance were also experimentally determined as follows:

A search coil of 75 turns was wound over one of the armature coils and connected to a suitable ballistic galvanometer. The fields were excited by a current of three amperes; different direct currents were passed through the armature for different posi-

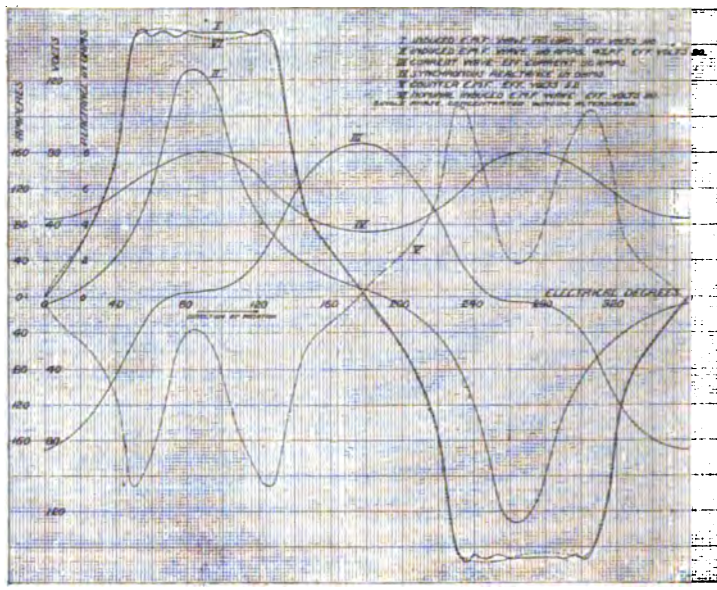

FIG. 12

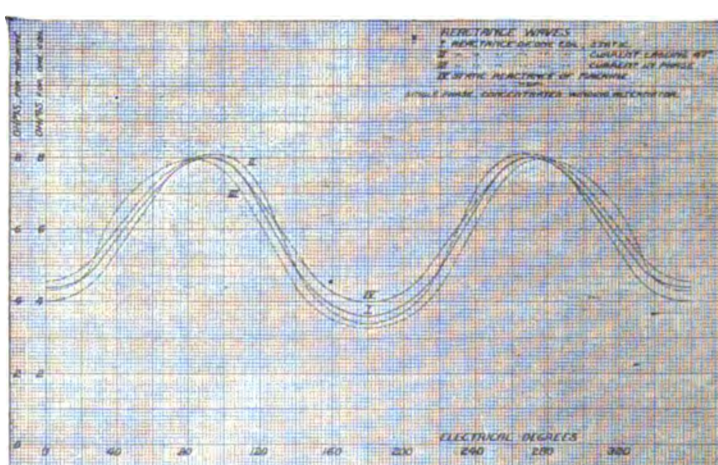

FIG. 13.

tions of the inductor lugs, and the throw of the galvanometer noted when the armature current was made or broken. Knowing the galvanometer constant, its readings indicated the total actual change in the number of lines threading the armature coils for different values of current and position of inductor.

Curve III, Fig. 10, gives the result in henrys when 100 amperes in the armature circuit was used, and is seen to correspond very closely to the values of reactance determined from the induction and current curves. A variation of armature current from a few amperes to 140 amperes gave virtually identical results.

The above curves of Fig. 10 show the variation of the total armature reactance for different positions of the inductor lug. The maximum reactance occurs when the inductor lug or pole is midway between two coils (2, Fig. 4); the minimum value when the inductor lugs are opposite armature coils (1, Fig. 4). The total armature reactance is thus seen to pulsate synchronously with the position of the inductor, maximum and minimum value occurring for inductor positions as above shown.

From the curves of total armature inductance with inductor position and armature current, the counter e.m.f., or e.m.f. which must be added to the real induced e.m.f. to give the nominal induced e.m.f., may be determined. Calling the counter e.m.f. at any instant, e, we have $\varepsilon = (d\,L\,i) \div (dt - 10^{-8}) = (1) \div (10^{-8})\,[(L\,d\,i) \div (dt) + (i\,d\,L) \div (dt)]$ volts. Where L is the instantaneous value of the total inductance per coil taken from Curve III, Fig. 10, and i the instantaneous value of the current in the coil, taken from current waves, Fig. 8.

The method is then simply to take the sum of any instantaneous value of L into the slope of the current wave corresponding to such value, and the instantaneous value of i corresponding to L into the slope of the inductance wave at the same time. This divided by 10^{-8} will give the instantaneous value of the counter e.m.f. of the coil. The process is a tedious one, but by plotting the curves to a large scale, quite accurate results may be obtained.

Applying the method to the case where the armature current is in phase with the nominal induced e.m.f., we have the results shown in Fig. 11. Curve I is the no-lead or nominal induced e.m.f. wave experimentally determined. Curve II is the real induced e.m.f. wave with 90 amperes and external power factor of 95% leading. Both these curves are the same as shown in

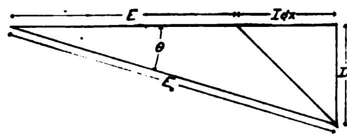

Fig. A.

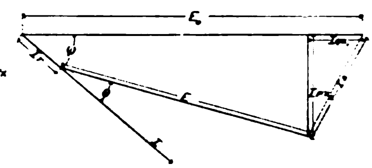

Fig. B.

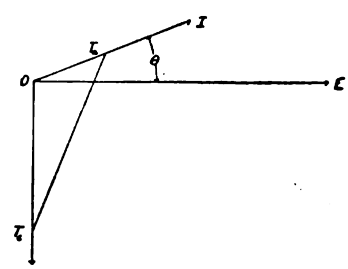

Fig. C.

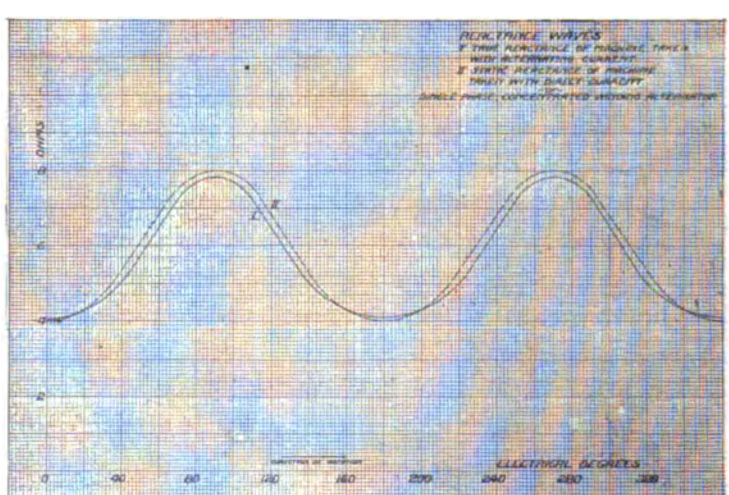

Fig. 14.

Fig. 7. Curve III is current wave, Curve IV the reactance wave and Curve V is the c.e.m.f. wave calculated from the equation as given above. Adding Curves V and II we have Curve VI, which should be identical with Curve I. Although not identical, the agreement between the two is extremely close.

If the equivalent sine wave or the c.e.m.f. wave is determined, it will be found to lag 90° behind the equivalent sine wave of the real induced e.m.f. wave. The effective value of the c.e.m.f. is 65 volts; the effective value of the nominal induced e.m.f. is 110 volts; and the effective value of the real induced e.m.f. is 107.5 volts, which together nearly form the right angled triangle that would be expected, as this c.e.m.f. is practically all due to the variation of induction set up by the cross-magnetizing currents of the armature. Dividing the effective value of the counter e.m.f. by the effective armature current, we have .722, a coefficient measuring the effect of cross-magnetization.

Applying the same method when the armature current lags by practically 90° behind the nominal induced e.m.f., we have the results given in Fig. 12. Curve I is as before the no-load or nominal e.m.f. wave. Curve II is the real induced e.m.f. with 110 amperes, lagging 85° from the nominal induced e.m.f. Curve III is the current wave; Curve IV the reactance wave; and Curve V the derived c.e.m.f. wave. Adding Curves II and V, as before, we have Curve VI, which again very closely corresponds to Curve I.

Determining the equivalent sine wave of the c.e.m.f., it will be seen to lag 90° behind the equivalent sine wave of current, but as the current lags practically 90° behind the nominal induced e.m.f., the c.e.m.f. wave is almost exactly in opposition to the nominal induced e.m.f., instead of being at 90° from it,as was the case with in-phase current. The effective value of the nominal induced e.m.f., is 110 volts; the effective value of the real induced e.m.f. is 50 volts; the effective value of the counter e.m.f. is 52 volts; this latter being virtually the difference between the first two. Dividing again the effective value of the counter e.m.f. by the armature current, we have .45, a coefficient now measuring the demagnetizing effect instead of the cross-magnetizing effect, as before.

It is thus seen that in this type of alternator, having a variable magnetic reluctance—and the statement is true for other types as well, as will be seen later—the e.m.f. vector representing the effective armature m.m.f., reaction and cross-magnetizing effect,

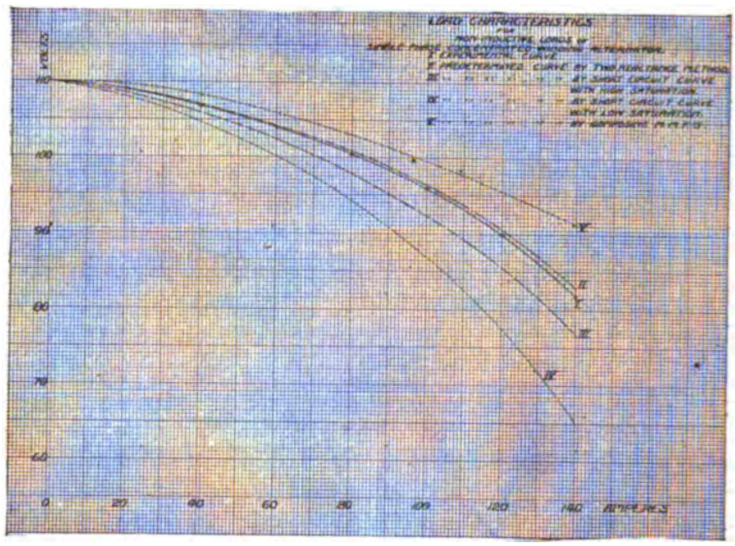
LOAD CHARACTERISTICS
VOLTS
110
100
90
80
70
60
0
20
40
60
80
100
120
140
AMPERES

Fig. 15.

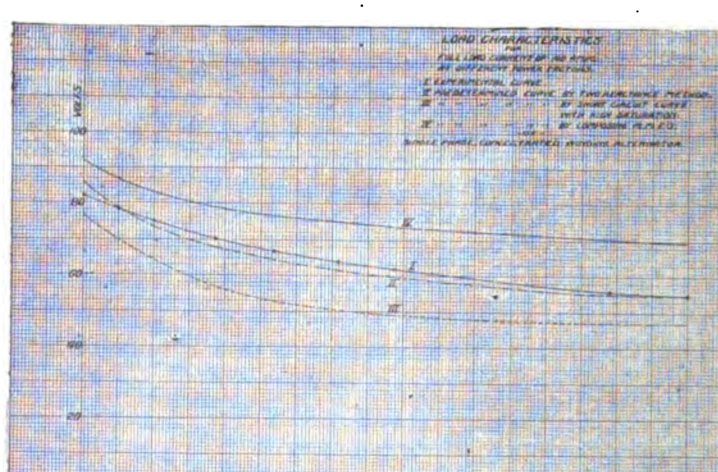
LOAD CHARACTERISTICS
VOLTS
100
80
60
40
20
100%
95%
90%
85%
80%
75%
70%
65%
60%
LAG
POWER FACTOR OF LOAD

Fig. 16.

varies not only in magnitude but in angular relation to the nominal induced e.m.f. from 90° to 180°, as the power factor of the total circuit varies from unity to zero.

In Fig. 13 are given in ohms the inductance curves I, II and III of Fig. 10, reduced from henrys, and an additional curve, IV, giving in ohms the total inductance of the machine for different positions of the inductor lugs, the 10 armature coils being all in parallel. It will be noted that the adjacent minimum values for this latter curve are the same, and equal to one-tenth of the mean of the adjacent unequal minimum values of reactance for one coil, as a little consideration will show should be the case.

ALTERNATOR REGULATION, INDIRECT METHODS FOR DETERMINATION.

The term " synchronous reactance " has been very generally used as combining the effect of armature reaction and the stray field due to the cross-magnetizing effect of the armature current, in the determination of alternator regulation; and, properly measured as the resultant of the demagnetizing and cross-magnetizing armature m.m.f., will give correct results. But, in general, it cannot be determined as a result of a single observation, as is ordinarily assumed.

Usually the synchronous reactance is determined from the short-circuited characteristic at low, or comparatively low, field excitations, the method of procedure being to short-circuit the armature through an ammeter and vary the exciting current until full load armature current is reached. The value thus obtained, however, will be incorrect for the following reasons: The field excitation being much below normal, the quadrature armature current will have a much greater proportional demagnetizing effect than when the field is fully excited; and further, in general, the field due to the cross-magnetizing effect of an equal in-phase armature current is greater than the diminution of field flux to the quadrature current. If the latter were equal in a particular machine, and the synchronous reactance were determined with normal field excitation and full load quadrature current, its use would lead to correct results. If the demagnetizing effect of a given quadrature current is not equal to the cross-magnetizing effect of an equal in-phase current, as in general it is not, one may be determined as a function of the other, as will be shown below. The demagnetizing effect of varying quadrature armature currents with full field excitation

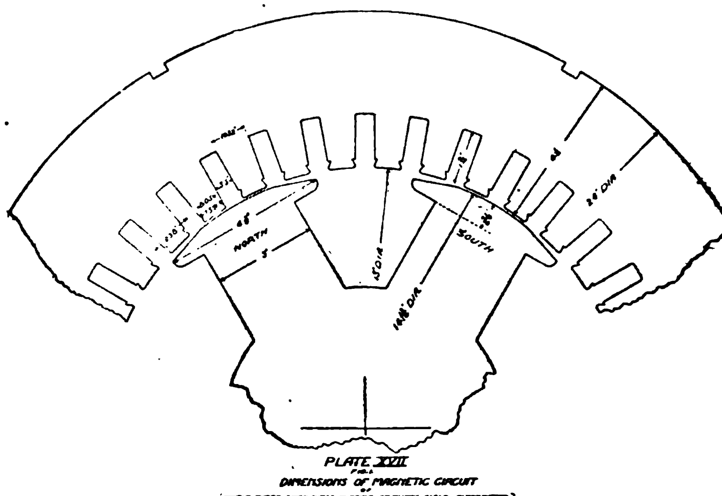

Fig. 17.

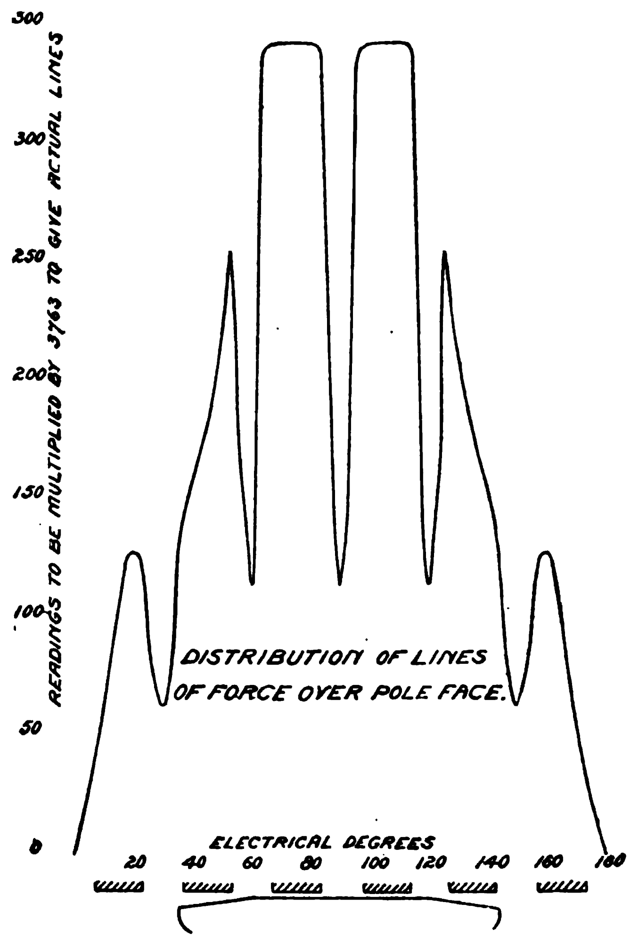

Fig. 17 b.

may be determined by working the alternator on a purely reactive load.

When the armature current lags behind the nominal induced e.m.f., by an angle between 0° and 90°, it may, of course, be regarded as made up of two components; the in-phase component, equal to the current multiplied by the cosine of the angle between the current and nominal induced e.m.f., and the quadrature component, equal to the current by the sine of the same angle.

Figure A. illustrates a method, which we will call the short-circuit characteristic method, used for the determination of alternator regulation. E is the terminal e.m.f., equal to the real induced e.m.f. when the armature ohmic drop is negligible. $I\,Q'\,x$ is taken as the component of the e.m.f. consumed by synchronous reactance corresponding to the demagnetizing effect of armature current. $I\,P'\,x$ is taken as the component of the e.m.f. consumed by synchronous reactance corresponding to the cross-magnetizing effect of armature current. x is the synchronous reactance determined from ordinary short-circuit characteristic with low field excitation; and P' and Q' are respectively the power factor and the inductance factor of the external load. From the diagram, we have:

$$E = \sqrt{E^2_0 - (I P' x)^2} - i\,Q'\,x$$

Applying this method to a given machine, it will generally be found to regulate better than the formula indicates, for the reason that the method of determining the magnetizing component of synchronous reactance gives too high a value for it. Other errors involved in the formula are the use of P', Q', as power and inductance factors of the load, instead of the power and inductance factors of the total circuit, armature and external load; and the assumption that the cross-magnetizing component of the synchronous reactance and demagnetizing component are equal.

Another approximate method, which we will call "composing m.m.f. method" (see *L'Endustrie Electrique*, December, 1899), is illustrated in Figure C. Referring to the figure, $O\,E$ is the real induced e.m.f.; $O\,I$, the current lagging by an angle θ behind the terminal volts. The armature ohmic drop is assumed to be negligible. On $O\,I$ is set off $O\,T_a$, the field m.m.f. necessary to overcome a quadrature current equal to I, determined from the

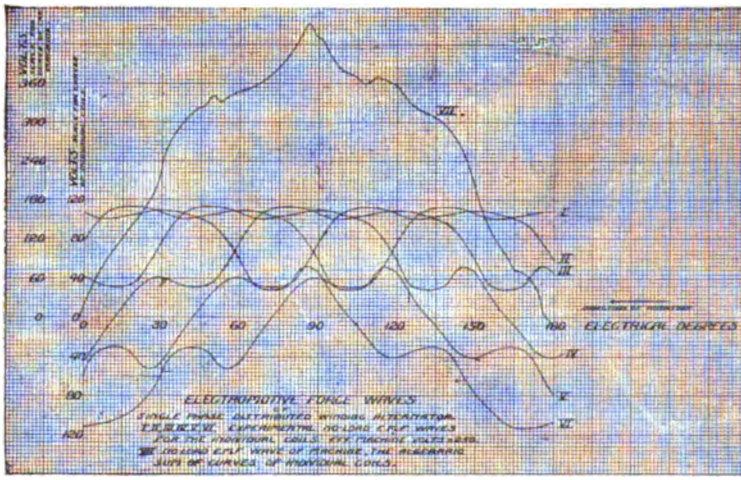
ELECTROMOTIVE FORCE WAVES
ELECTRICAL DEGREES

FIG. 18.

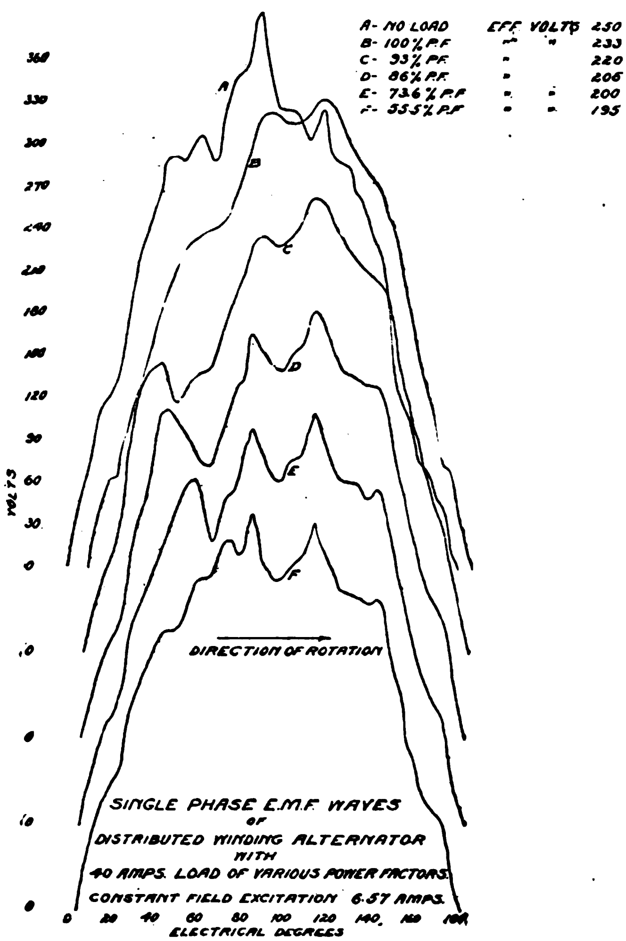
A- NO LOAD EFF. VOLTS 250
B- 100% P.F. " " 233
C- 93% P.F. " 220
D- 86% P.F. " 206
E- 73.6% P.F. " " 200
F- 55.5% P.F. " " 195
VOLTS
DIRECTION OF ROTATION
SINGLE PHASE E.M.F. WAVES
OF
DISTRIBUTED WINDING ALTERNATOR
WITH
40 AMPS. LOAD OF VARIOUS POWER FACTORS.
CONSTANT FIELD EXCITATION 6.57 AMPS.
ELECTRICAL DEGREES

FIG. 19.

short-circuit characteristic. From T_a is struck an arc with a radius equal to the field m.m.f. The distance to the point where this arc intersects a line drawn at right angles to $O\ E$ is taken as the effective m.m.f., producing the real induced e.m.f., E. Having $O\ T_c$ or the effective m.m.f. acting, E is determined from the saturation curve. As will be readily appreciated, the principal objections to this method are the assumption that the alternator works on a straight line characteristic, and the neglect of armature self-induction.

The following method, which we will call for convenience "the two reactance method," has been found to give accurate results when applied to a number of alternators of widely different types.

The demagnetizing effect of different quadrature currents is determined at full load field excitation, and not at an excitation just sufficient to circulate full load current through the armature on short-circuit, as is ordinarily done.

The armature, instead of being short-circuited, is operated at constant full load field excitation on a suitable variable reactance and the difference between the voltage given by the saturation curve and terminal voltage is noted. The voltage thus obtained divided by the current gives the value of the demagnetizing component of the synchronous reactance corresponding to normal conditions of machine operation. The cross-magnetizing effect for different in-phase currents is taken as equal to the demagnetizing component of the synchronous reactance multiplied by the ratio of the total inductance of the armature, with the inductor lugs in position shown in I, Fig. 3, to the inductance of the armature with the inductor lugs in the position shown in II, Fig. 3. The inductance is determined by passing through the armature, from external source, a suitable alternating current when the lugs are in the position just named, and the fields fully excited.

Curve I, Fig. 14, is a complete curve of armature reactance at 60 cycles with the inductor in the positions named and intermediate ones. The ratio of maximum to minimum values of this curve is the ratio referred to above.

Curve II, Fig. 14, is one obtained by the ballistic method, and is seen to agree quite closely with Curve I.

Using the values so obtained for the demagnetizing and cross-magnetizing components of synchronous reactance, the Figure B due to Blondel, properly expresses the relations of e.m.f. and currents in the armature of an alternator under full load condi-

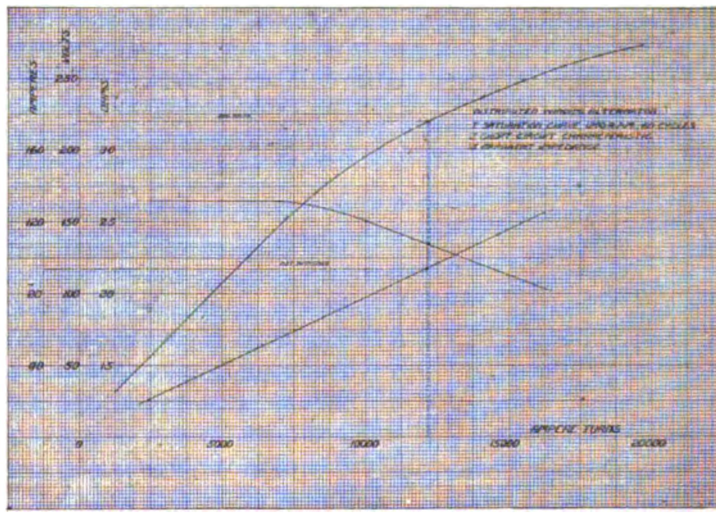
AMPERES
VOLTS
OHMS
250
160
200
30
120
150
25
80
100
20
40
50
15
0
5000
10000
15000
20000
AMPERE TURNS

FIG. 20.

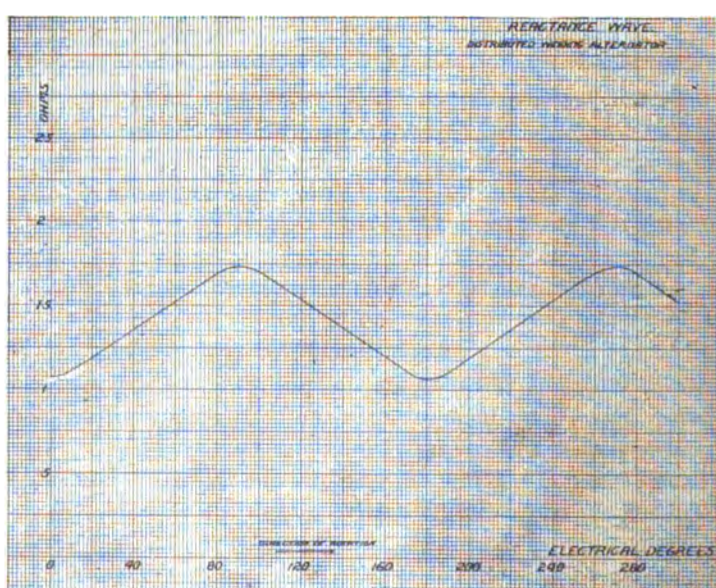
REACTANCE WAVE
DISTRIBUTED WINDING ALTERNATOR
OHMS
2.5
2
1.5
1
.5
0
40
80
120
160
200
240
280
ELECTRICAL DEGREES

FIG. 21

tions of operation. E_0 is the nominal induced e.m.f.; φ, the phase angle between the current and the nominal induced e.m.f.; θ, the phase angle between the current and the terminal voltage; X, the demagnetizing component of synchronous reactance; X_2, the cross-magnetizing component of synchronous reactance; P and Q, respectively, the power and inductance factors of the whole circuit; $I\,r$,the ohmic drop; and E, the terminal e.m.f.

Application to Inductor Alternator.

The different indirect methods for determining the variation of terminal voltage as a function of the armature current and the power factor of the external load for constant field excitation, stated above, have been applied to the 15.4 k.w. inductor alternator, shown in Figs. 1 and 5, and compared with directly observed results.

The saturation curve, short-circuit characteristic, and the curve of synchronous impedance for this alternator were given in Fig. 6. Curve I, Fig. 15, gives the actual observed load characteristic for non-inductive load at a constant field excitation of 3 amperes.

Curve II is a calculated curve by the two reactance method. It is seen to agree exceedingly well with the observed curve.

Curve III is the calculated curve by the short-circuit characteristic method, using the value of the synchronous reactance obtained with full field excitation, the short-circuited armature current being 225 amperes, or 85 amperes above the normal full load current.

Curve IV is a calculated curve by the short-circuit characteristic method, using the value of the synchronous reactance obtained with a field excitation just sufficient to circulate the full load current of 140 amperes through the armature.

Curve V is the calculated curve by composing m.m.f.'s.

It will be noted that while the terminal voltage by the short-circuit method, for a given armature current, is much less than the observed terminal volts, the agreement becomes much more close when the values of the synchronous reactance are obtained with high field excitation. The method of composing m.m.f.'s gives much too high a value for the terminal voltage, as will be expected.

In Fig. 16 are shown the results of the same methods applied to the case of constant armature current with variable external

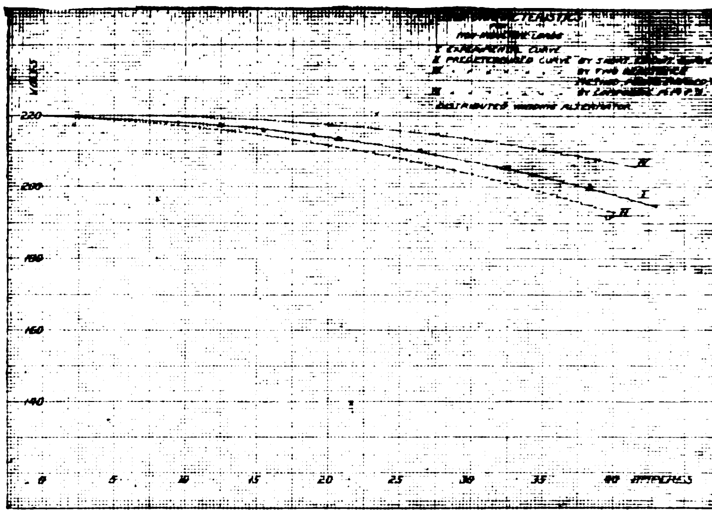
VOLTS
220
200
180
160
140
0
5
10
15
20
25
30
35
40 AMPERES
I
II
IV

FIG. 22

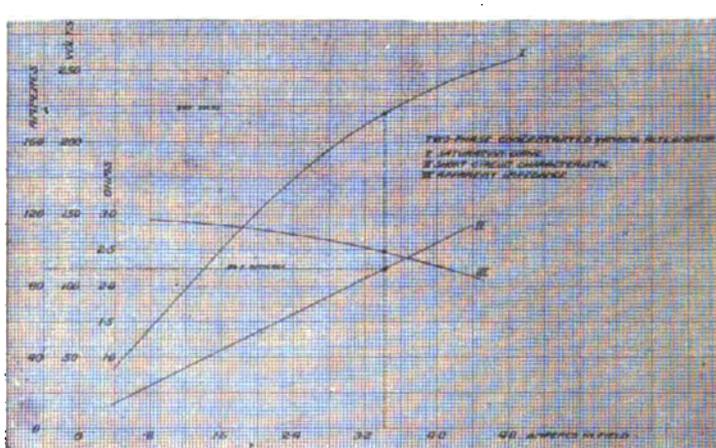
AMPERES
VOLTS
OHMS
250
200
150
100
50
0
8
16
24
32
40
48 AMPERES IN FIELD
I
II
III

FIG. 24.

power factor, as compared with the observed results.

Curve I gives the observed values of the terminal e.m.f., with power factor, for constant field current of 3 amperes and constant armature current of 140 amperes. Curve II is that calculated by the two reactance method; Curve III by the short-circuit characteristic with high field excitation; and Curve IV by composing m.m.f.'s.

Again, the two reactance method is seen to give accurate results, while the short-circuit characteristic method gives, as before, too small values, and the method of composing m.m.f.'s too large values of the terminal e.m.f.

Application to other Types.

A second machine upon which a number of tests were made was of the revolving field, distributed armature winding type, the magnetic circuit of which is shown in *a*, Fig. 17.

In addition to the load characteristics observed and determined by the different methods, tests were made of the induction distribution under the different conditions; the wave form of the terminal e.m.f. was analyzed into its component wave forms, due to the individual armature coils; and the conditions affecting the change of wave form with character of load were studied.

In *b*, Fig. 17, is given the no load induction distribution with the field magnet in the position shown, the fields being excited to give normal terminal voltage. This was obtained by means of a ballistic galvanometer and suitable exploring coils in the usual way. It will be noted that the larger part of the induction enters the armature through the teeth, as might have been expected, but about one-third of the induction, in the case of the teeth immediately opposite the pole, passes into the armature by way of a slot due to the high induction intensity in the teeth.

Curves I, II, III, IV, V and VI, Fig. 18, are the individual e.m.f. waves for each of six successive angularly displaced armature coils in series, when the machine is connected as a single phaser. Curve VII is obtained by taking the algebraic sum of the instantaneous values of the first six curves, and agrees very closely with the no-load observed e.m.f. wave, Curve IV, Fig. 19. These curves show most clearly the advantages of distributed windings as regards wave form, for while the e.m.f. from an individual coil, as Curve IV, is a very flat topped wave, and somewhat similar to the no load e.m.f. wave of the concentrated winding inductor alternator (Curve I, Fig. 7), the machine

DIMENSIONS OF MAGNETIC CIRCUIT
OF
TWO-PHASE CONCENTRATED WINDING INDUCTOR ALTERNATOR.
DOTTED LINES SHOW PATH OF MAGNETIC FLUX.

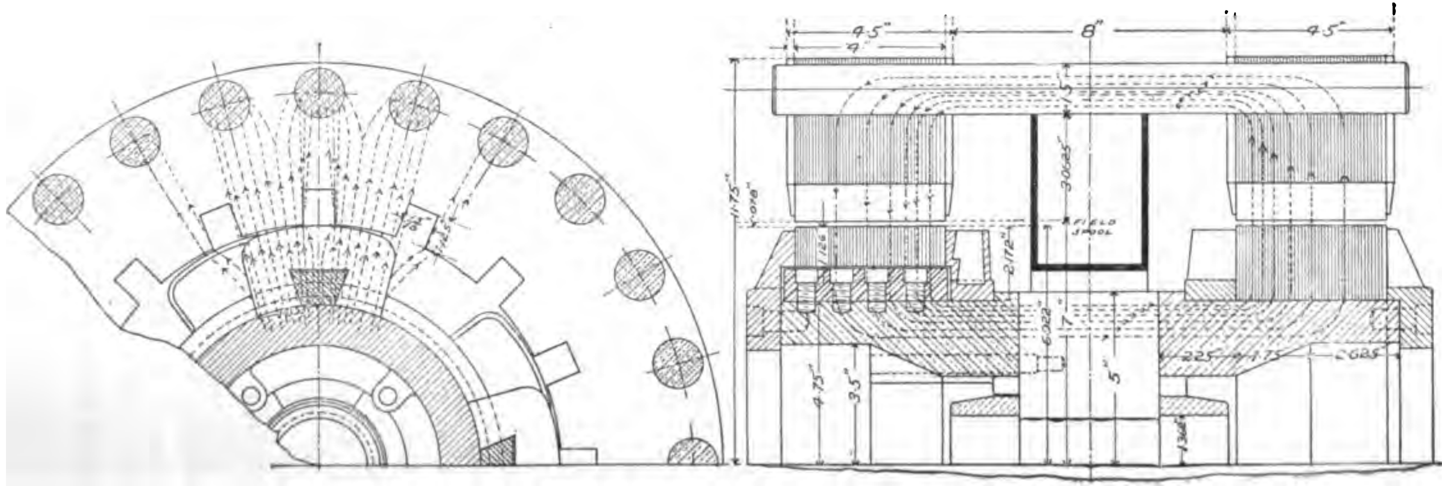

Fig. 23.

e.m.f. wave, which is the resultant of six such waves displaced by 30°, is very nearly sinusoidal.

If a machine is desired which will give not only an extremely close approximation to a sine wave e.m.f. at no load, but also shall hold such wave form with changes of the load, the number of slots per phase per pole must be made as large as practicable, and the induction distribution such that the e.m.f. waves for the individual armature coils are also as near to sine waves as possible.

In Fig. 19 are given a series of e.m.f. waves with constant field excitation, a constant full load armature current of 40 amperes, and power factors varying from unity to .55. It is to be noted that while the wave form changes with the power factor, the change is by no means so great as in the case of the concentrated winding inductor type.

Curve I, Fig. 20, is the saturation curve of the machine shown in Fig. 17; Curve II, the short-circuit characteristic; and Curve III, the synchronous impedance calculated from Curves I and II. At 4.6 amperes exciting current, the impedance is 2.6 ohms, the effective resistance being .186 ohms, the reactance 2.31 ohms.

The complete reactance wave for this machine, obtained by sending through the armature an alternating current, the field poles being in different positions, is shown in Fig. 21. The ratio of maximum to minimum values of the reactance is seen to be 1.625. As the demagnetizing component of synchronous reactance from the short-circuit characteristic is 2.31 ohms, the cross-magnetizing component of the reactance is $2.31 \times 1.625 = 3.75$ ohms.

The three indirect methods for the determination of alternator regulation before discussed, were applied to this machine and compared with the experimental curve. The results are shown in Fig. 22. Curve I is the experimental or observed load characteristic for a non-inductive external load. Curve II is calculated by the short-circuit characteristic method, high field excitation. Curve III, determined by the two reactance method, is identical with the experimental curve, Curve IV, determined by composing m.m.f.'s. The correspondence between the observed and calculated value by the two reactance method is highly satisfactory.

The magnetic circuit of the third machine tested is shown in Fig. 23. The machine is a 10 k.w., 220-volt, 60-cycle, two-phase

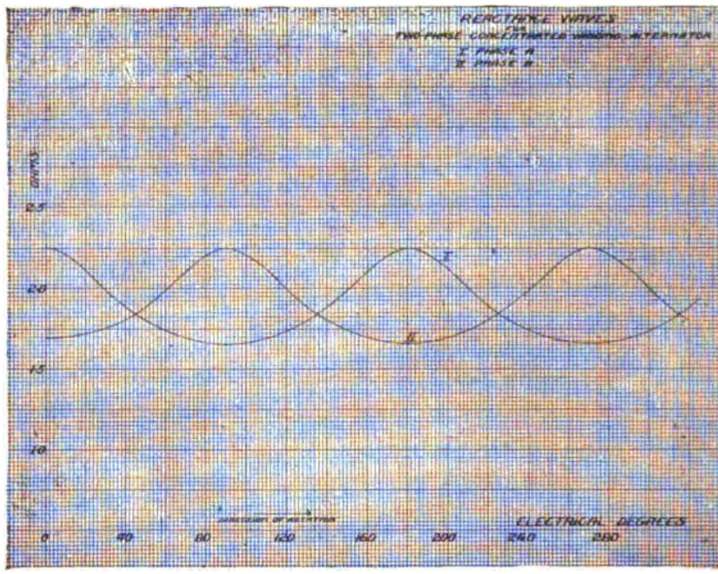
REACTANCE WAVES
OHMS
25
20
15
10
ELECTRICAL DEGREES
0 40 80 120 160 200 240 280

Fig. 25.

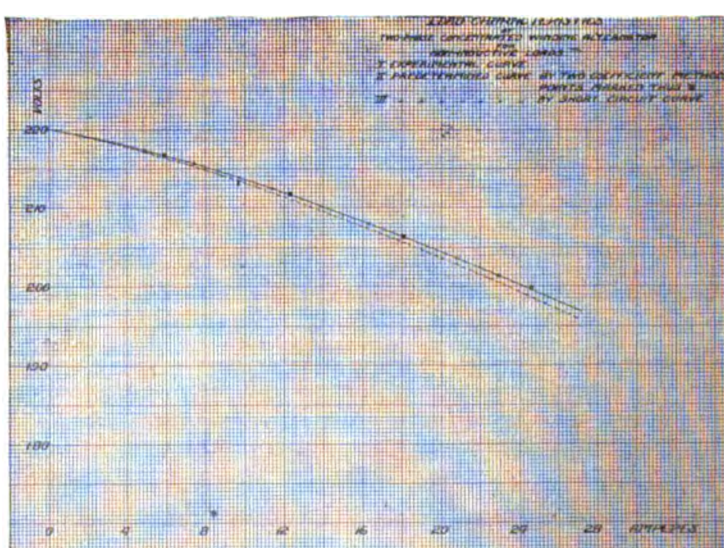
VOLTS
220
210
200
190
180
0 4 8 12 16 20 24 28 AMPERES

Fig. 26.

when both cannot be conveniently had, I am strongly in favor of sacrificing quantity for quality. In this connection I wish to remove the onus which is wrongfully placed upon the men who actually educate the electrical engineer. The professor of electrical engineering has, so to speak, " caught it " rather hard, and, in my opinion, most undeservedly; he has been held responsible for many failures in turning out competent "engineers," which ought properly to be credited to some of his colleagues in the faculty—notably the professor of mathematics. The truth is that the mathematical preparation of the students is, in a large number of cases, quite incomplete and inadequate. That is why they stumble in the analytical and applied mathematical studies. Dr. Perrine's allusion to the course in differential equations, which he had such difficulty in arranging, is an interesting revelation. As the result of extended observation, and of the confidences of many engineers and students during the last fifteen years, I have come to the conclusion that much of the deficiency in engineering education, both theoretical and practical, is due to the difficulties which are *made* instead of *removed* for technical students, by their teachers in mathematics. I have begun to look upon mathematics, both pure and applied, as taught by many college professors, as a means of befogging the pupil, of obscuring his mind, of literally putting difficulties in his way, instead of enlightening him and facilitating his progress, as should be the case with proper teaching. I have two nephews now following engineering courses. I found that both had difficulty in keeping up with the course in calculus. I undertook to help one of them at his request. I found that he lacked knowledge of the fundamental preliminary principles forming the groundwork of the subject; it was like trying to learn square root before learning multiplication or division. When I inquired whether these things had not been taught him and why they had not been learned, even before entering upon this study, I learned that the young man, in common with the great majority of his class, had been groping and stumbling in the dark during the entire term. Only a few of the students were still pretending to follow the professor, who had been, all this time, to use their own words, " talking to himself and over our heads." The professor had evidently done his best to " keep ahead " of the students, and he had run no danger of being overtaken. The young man naturally had " mathematical indigestion," in rather aggravated form, as the result of trying, for weeks, to gorge his mind by main strength of memory, with undigested mathematical " pottage."

As pointed out in the Presidential address, by Mr. Steinmetz, (who may well be deemed an authority on subjects mathematical) the memory will not retain formulæ which the mind has not *analyzed* and *understood.* I took advantage of a vacation week to give the young man a new start, by going back with him to the very beginning, and laying a solid foundation of *elementary*

fundamental knowledge. The difficulties complained of vanished quickly, and the young man then made satisfactory progress. His natural ability is such as to force upon me the conclusion that his deficiency was entirely due to inadequate teaching.

Quite recently, I had occasion to help another young man, who is a recent graduate of a well-known technical school, to take a fresh start in some of his mathematical studies, including calculus. He also had been a sufferer from the same kind of indigestion, pretty much for the same reason. I could cite at least a dozen similar cases; and in all of them I really blame the teacher more than the pupil. It is a well-known fact that the percentage of graduates who retain sufficient interest in their mathematics to care to keep up their knowledge and increase it, after leaving school, is extremely small. The great majority proceed to " forget it " with a rapidity which almost savors of alacrity; and, in come cases, they become empirical to an extent which makes even a non-graduate " practical " engineer blush. What is the cause? *Mathematical dyspepsia.* The mathematical " indigestion " from which the students suffered for four years, while in college, has become chronic—it has become " dyspepsia," and mathematics are no longer palatable because " they never did agree with him." He literally, and to use his own words, " has had already more than he wants of it." He therefore falls into " practical " ways, and is fortunate if he does not evolute to the point of wondering what mathematics were ever invented for, anyhow.

Having had to teach myself mathematics (beyond the mathematics acquired in a high school course), and being a rather poor pupil, I needed very patient and somewhat scientific teaching. That is why I have given so much attention to the study of methods of teaching. I still am engaged in the study, both as the pupil and his teacher. Mathematics are a part of my " post-graduate work," and I find it interesting and profitable to devote many hours of leisure to them. I have had occasion to help others to get knowledge of the subject, and I have discussed the matter of teaching mathematics with many teachers, among whom I will mention Dr. John Perry of the Royal Technical College, London, whose name stands among the foremost in electrical science and in engineering, and stands in the very front rank as a mathematician and a teacher of mathematics. During the visit of our INSTITUTE to England in 1900, it was my pleasure to meet Dr. Perry on many occasions (he then being President of the Institution of Electrical Engineers), and to study him as a man, as a scholar and as a teacher; and, in common with all the American members of this INSTITUTE who were guests of the Institution of Electrical Engineers, I learned to admire and esteem him greatly. I had occasion to discuss with him the subject of teaching mathematics, both from the standpoint of pupil and teacher (both sides being interesting to me for the reason already stated); and I was very much pleased and encouraged by what I considered his very sensible views on the subject. He was the first mathematical teacher that I had met who had enough imagination and judgment to put himself in the pupil's place, and to properly appreciate the pupil's difficulties and note his needs. I found with pleasure that he had been for some time preaching reform in methods of teaching mathematics in England. He had found as the result of extended experience as a teacher, that only few mathematicians are " born "; that the others have to be " made "; that the present methods of " making " them were not fully satisfactory, and might be greatly improved. He gave me a copy of his " Practical Mathematics,"—a summary of six lectures delivered to workingmen." and I would recommend every engineer, and even every teacher, to procure and read these lectures. I read the book on the steamer, and found it so good, that after I arrived, I procured a half-dozen copies, which I sent to various friends who, I knew, would be grateful for light on the subjects discussed by Dr. Perry.

At the last engineering congress, at Glasgow, in 1901, Dr. Perry read a paper on the teaching of mathematics, which I also recommend to every man who has had to struggle to get light on that subject, whether he has been through a university or not. This paper formed the nucleus or the starting point of an interesting discussion, constituting an able symposium, in which the ablest mathematical men in England, from Lord Kelvin down, took part; hence it is not the expression of a few desultory or sporadic thoughts on the subject, but it represents the entire analysis of the question of teaching mathematics. You will find that the conservative teachers, " the Euclidians," do not hit Prof. Perry very hard, notwithstanding the extremely radical views which he took on the subject. I also recommend Dr. Perry's presidential address before the Institution of Electrical Engineers as most profitable and wholesome reading for engineers. It seems to me that many mathematical authors especially in America, write their books, same as some professors lecture, for an " audience " of professors and critics rather than of students. The mathematical professor should use his knowledge to *impart knowledge* to his pupils. He too often uses it to *impress them with it*, merely. In discussing methods of teaching with some of them—not of Dr. Perry's kind but of the old-fashioned kind—I have been surprised to see the importance which they ascribe to the adjectives *terse* and *rigorous*. Many of them apparently think that they lose dignity unless they are strictly " terse and rigorous." Because, figuratively speaking, they themselves can clear almost any obstacles with a stride or a jump, they assume that the poor student ought, can and must do the same. The student, therefore, finds himself, in most cases, just as much handicapped as if he were trying to keep up with a fleet-footed runner, who is also a good, all-around and well-trained athlete. When the steps of the reasoning are too large for the mental grasp of the pupil, he memorizes them without understanding them, which means that he does not really learn the reasoning but takes it for granted. In such a case, mathematical study does not strengthen and discipline the mind, but does the very reverse. If, on the other hand, the pupil were led over a less steep and precipitous path, even though it were apparently a much longer path, he would not be so likely to lose courage or lack confidence in himself or his teacher, and, as I have found repeatedly, he would attain the goal more often, with less effort, and in less time, than he does by the orthodox " terse and rigorous " route. In this case the student, being able to see the steps without difficulty, can use judgment, instead of trying to rely wholly on memory, in following the road. His reasoning faculties are exercised and trained without straining the memory—which is, in my opinion, the most satisfactory method.

While it is true that there is no royal road to mathematical knowledge, it is certainly a great mistake, in my opinion, to imagine that the best road is along the line of maximum effort. I believe, on the contrary, that the best road lies along the line of least effort. I am not in sympathy with the idea of some teachers that it is necessary to make a thing difficult in order to have it well learned and remembered. We begin the physical training of children by light gymnastic exercises, not by physical efforts which would strain the athlete. The same rule should apply, *a fortiori*, in intellectual training, for the important physiological reason already noted, namely, that mental growth is essentially a slow process, which should never be forced. The intellectual gymnastics should be such as involve the least mental *effort*, and produce the most intellectual *exercise*. One orthodox teacher of mathematics argued that the teaching should not go so far in elucidation, as to literally " put the dot on the i " for the student; I agreed; but I insisted that the pupil should nevertheless be taught that there *is* a dot, and where it ought to be put on that i, instead of being allowed to guess it. In this connection I wish to call attention to the striking contrast between French and American mathematical text-books. The French mathematical teacher believes in the " rigorous " just as much as his American colleague, but he has no sympathy for the " terseness " which is secured at the expense of *lucidity* and *intelligibility*. He does not hesitate to devote pages, sometimes, to the elucidation of topics which the American text-book treats " tersely " in a short paragraph. He follows the line of least effort. His book is more bulky, but it is far more easy to " digest " than the American text-book. Instead of being a cause of intellectual dyspepsia, it is, on the contrary, a prophylatic and a cure for it. Instead of destroying the taste and aptitude for mathematical study, it stimulates and develops them. I would advise all science students to study and master the French language, if only for the assistance which it will place at their disposal in their studies in pure and applied mathematics. There are many

American teachers, especially among those who write text-books, who could profit by the same advice. A few of them have already done it, or are doing it, I am glad to say, and it is to be hoped that their study of books, such, for instance, as Briot's admirable text-books of "lessons," (in algebra, trigonometry, analytical geometry, etc.), which have run through fifteen or more editions, may inspire some ideas of reform in methods of teaching. It may be a mere accident or coincidence, but the fact is interesting, that by far the most thoroughly trained and able young graduate engineers in a mathematical sense, whom I have ever had in my employ, were the product of French methods of teaching and of French schools.

In concluding this portion of the discussion, I wish to express the opinion that Dr. John Perry deserves the applause and the gratitude of all who believe in mathematics, for the crusade of reform in methods of teaching which he has inaugurated. His recognized mathematical learning and scholarship, his international reputation as a scientist, his writings, his lectures, and above all, his long personal experience in teaching pure and applied mathematics, make him a most competent and authoritative judge and critic of methods of teaching mathematics. His opinion to the effect that reform is needed, may well be accepted as conclusive evidence that *it is* needed.

Dr. Perry will, I hope, forgive me for betraying his confidence, as I am now about to do, to the extent of disclosing some of the "details" of his method or "art" of teaching, which are quite pertinent to this discussion, and which show, incidentally, that he can teach other things than mathematics and engineering, and with success. Reference is made in some of the papers, especially in Dr. Sheldon's paper, to the importance of developing or disciplining the emotional and æsthetic sides of the student's nature. Dr. Perry also lays great stress on the cultivation of the higher mental attributes, more especially the *imagination*, the development of which he deems of great importance as a factor of the student's progress in his studies and his success in technical work. He informed me that he studies carefully the pyschology of each of his pupils, and when he finds the imagination deficient, he proceeds to apply a "stimulant" in the form of non-technical general reading. He showed me, in his study, at the Royal College, a well-stocked library, which he has gathered together almost for that express purpose. In some cases he may "prescribe" and "administer" poetry, in others, history, general literature, travels, romance and adventure, according to the "case." I was surprised to find Cooper's novels, and most of our standard classical American novels, in his lists of authors. I was also surprised and gratified to note Dr. Perry's wide knowledge of our literature; but I was still more surprised at the scientific manner in which he used it as a stimulant for the imagination, and as a "developer" of the student's broader culture. He related numerous cases, giving the "diagnosis" and the "treatment" and the gratifying results accomplished. He cited cases where a "cure" or, at least, great improvement was effected by the perusal of a few stirring novels and an occasionally friendly "talk." His pupils all admit that he is a great and successful teacher, who has the rare faculty of retaining the attention and keeping up the interest of the students, and of infusing individuality into them. It is my opinion that Dr. Perry could teach many teachers valuable lessons in the *art of teaching.*

Before concluding, I wish to applaud heartily and to emphasize strongly the pertinent, well-deserved criticism made by Mr. Pearson, to the effect that the present methods of education are apparently too sordid, and aim too much at the *immediate* result, and too little at the *ultimate* results. The schools may not be altogether to blame for this. Prof. Esty distinctly advocates the kind of technical education "which aims not to make the graduate immediately successful in commercial life, but aims rather at ultimate success." Doubtless many of his colleagues hold or would like to hold this broader view, but the public, the parent and the student do not, unfortunately, take this broad view, and they have created a "demand" for the "other kind" of education. In justice, we must admit that it is they, and not the schools or the teachers, who are "sordid." They too often consider engineering to be a "business" instead of a vocation. The student is too often the raw material from which his parents, friends and advisers want the professor to turn out, not an engineer, but a wage-earner. The young man has chosen this or that branch of engineering, not because he really deems himself most apt and fitted for it, but because "there's money in it." In other words, the end in view is *dollars*, as many and as quickly as possible, rather than what it ought to be, namely, *attainments* primarily, and *emoluments* secondarily. This is only a very natural propensity perhaps, in the age and in the land of the "mighty dollar." Like Mr. Pearson, I do not admire this propensity, even though it be growing in "popularity." It demoralizes the scientific spirit, and tends to lower the standard of professional ethics. I am often asked by young men, just out of technical schools, what is the best thing for them to do, or what is the best way for them to "start." I have always made it a point to begin the answer to their questions by asking them questions, such as: "Do you wish to go *quickly* or to go *high*? What is your ultimate object in this 'business?' Do you merely want to become a hundred-dollars-a-month man or so, or do you wish to attain the pitch, the standing, the value, call it the "earning capacity," if you will, of a thousand-dollars-a-month-man? The young man generally admits that he would rather join the one thousand dollar class; but when I explain to him the laborious process, and point out the long tedious roads which have to be followed in order to become qualified for that class, he very often becomes discouraged, and concludes that he will take the short cut route, and trust to "luck" or "business ability" to get above the $100 class. The truth is, that in qualifying for the $1,000 a month class, he must spend more years in training "*at both ends of his course*" *i. e.*, both after and before graduation; in other words, he must *broaden*, *deepen* and *strengthen* his education in every way possible. He must not expect immediate results; he must not start with the notion that he is at once so valuable to his employer; but he must spend years and years building the foundation, acquiring practical knowledge, acquiring theoretical knowledge, fortifying and consolidating theory by practice, and solidifying his theoretical knowledge, developing the qualities of individuality, originality and resource, until he is able to grasp difficult, intricate problems, and handle them with little or no difficulty. This means years of application and effort.

There is a valuable suggestion in Mr. Raymond's paper, in the statement that "the college graduates should consider that the knowledge gained at the university is only a start and not a suggestion of a finish." Every graduate ought to feel that as he leaves school he is entering upon a "post-graduate course," which is to last the rest of his useful life. I have been following such a course for the last twenty years, and I hope it may last twenty or thirty years longer.

I have confirmed by repeated observation the truth of Dr. Goldsborough's remark about the applicant for a position. The individual often spends too much effort in trying to get a position and too little effort in trying to keep it. I think it far better to spend time, even years, in getting ready to *fill* a good position than in seeking for it. The old proverb says: "He who deserves success shall command it." The engineers who are successful, (I mean as engineers, not necessarily as money-makers), carry out, as a rule, the spirit of that proverb; they symbolize its realization. They typify and dignify the doctrine that the "position should seek the man." They bestow their best efforts upon all their work, whether the task be imposing or humble. They are content to do little things long, until they can do them well, and to learn through them, and to progress from them to greater things. The time ultimately comes when they can utilize their knowledge to advantage and with financial profit; and oftentimes the longer the opportunity has been in coming, the better and more satisfactory it proves to be. Luck has far less and merit far more, to do with these things than is generally believed. Just as, in physics, water proverbially seeks and finds its level, so in human affairs, there is a force tending ever to place individuals at the proper levels. Shakespeare has expressed this force in terms of a "divinity which shapes our ends." Reverting again to Victor Hugo's quaint phrase, I would state that our "ends" are "shaped," oftentimes, not "because of" but "in spite of" our efforts to "rough hew them as we will." We often find the man whose object was pelf, fail to get that which was his sole object, whereas the individual whose primary aims are merit and worth, often "gets the emolument besides."

In conclusion, I may say that I am highly impressed by the general programme of "reformed" engineering education outlined in Prof. Esty's paper, in the concluding paragraph. I am also glad to find some authoritative expressions of sentiment favoring better and broader preliminary general education, more thorough even if less extended theoretical and practical technical training, and in general, commending the process which leads to the best ultimate rather than to the most immediate results.

MR. SKINNER:—As a representative of the engineering department of a large manufacturing concern, I wish to agree most heartily with all that has been said in favor of the broad education of the engineer. I fully appreciate the difficulty mentioned by Prof. Goldsborough, that many students, particularly in the West, are, for financial reasons, unable to continue their studies for the length of time necessary to get this broad education. I am surprised, to say the least, at the grounds taken by Mr. Raymond, that specialization should begin so early. I think we are all more or less familiar with the phenomenon of the aging of steel after it is annealed. I am sure that men with such training as Mr. Raymond advocates will age very rapidly, indeed, when put through his annealing process.

PRESIDENT STEINMETZ:—Gentlemen, discussion is still in order. I call upon Mr. R. W. Pope, who was going to give a few minutes' talk.

SECRETARY POPE:—I just wish to say that I have not sufficient command of language to express my appreciation of the attendance here, and what the people of my native town have done for the engineers, and the fact that we have been brought together under such delightful circumstances. I obtained Mr. Arnold's permission before he left, to join me in support of Mr. Mailloux's argument that we could not learn too many languages, and if there is one thing that Mr. Arnold and I regretted, it was that we knew so little of French when we were together in Paris.

In my school days, which with the exception of one year were passed in Great Barrington, a college education was scarcely thought of unless the pupil intended entering the profession of law, medicine or the ministry. My school education ended with my fourteenth year. I have always regretted that this was the case, as I now realize that there must be a feeling of satisfaction due to college training that has been lacking in my own experience. I have, however, trained myself to believe that the education of a man is a most important step in his career, but that the result depends very largely upon the quality of the material to be dealt with. It has been stated in this discussion that the profession of electrical engineering dates back only about fifteen years, and I have therefore thought it of interest to include in my remarks an editorial written by me seventeen years ago which appeared in the *Electrician and Electrical Engineer*, October, 1884, as indicating the views of one who at that time had been engaged in railroad and telegraph work twenty-five years.

TECHNICAL EDUCATION.

" There is no more important question in the whole range of social topics than that of education, and public attention has been directed to it both in Europe and America, for the purpose of devising, if possible, some system which would more effectually teach what the pupil may be expected to practice when he reaches maturity. The fact that a student when obtaining a classical education devotes to that work the very years when he should be gaining a practical knowledge of the handicraft by which his living must be earned, has in a measure, obliterated the old idea that every boy with brains *ought* to go through college. The value of such a training is by no means to be underrated, but it should not be exacted without proper consideration of the future, and every parent should be able to discern whether a boy of fourteen has a decided leaning toward the so-called learned professions, science or mechanics. Whatever walk in life he may finally travel, he may not prove eminently successful, even if meritorious. Success, from a worldly point of view, is a matter of chance, as well as of merit; but moderate success, which brings contentment and happiness to thousands of humble homes, is but the application of honest industry and judicious economy to that line of duty which has finally been selected as the means of livelihood. This is the fundamental idea of a technical education. To what extent it should be carried out is still a matter of dispute. There can be, however, no good reason advanced why a bricklayer may not graduate from his special school, as well as a physician from a medical college. Practically the artisan would be the more perfect production of the two, for the reason that the elements that he deals with do not present such a variety of phases which require far more practical experience. In discussing the merits of technical schools, both their opponents and advocates are prone to lose sight of the value of experience. The amateur artisan, as well as the college graduate, in cutting loose from their Alma Mater enter the professional arena, and instead of humbly seeking further light as to the mysteries of their craft, endeavor to parade their superior attainments, get snubbed for their pains, and at once build up a feeling of enmity which years of association may not eradicate. The student should be constantly impressed with the idea that he is not *learning* a trade or profession, but merely learning how to begin, and then when he enters the vast field of labor, it will be in the more dignified garb of a skillful apprentice, rather than that of a bungling journeyman. He will thus escape much of the drudgery which usually falls to the lot of the youngest employes, for the reason that his time will be too valuable to be devoted to such service. Here it may be remarked that much of the animosity that exists against the introduction of new labor in the trades, is caused by the placing of incompetent hands, at low wages, in positions which they are not qualified to fill. Employers are also responsible for the existence of considerable ill-feeling, by not properly appreciating the value of long experience in certain branches of the service. A larger proportion of the spirit of humanity infused into those years of toil would, beyond question, materially increase the profits of nearly every branch of business."

In re-reading the above under the light of later experience, and in view of to-day's discussion, I will merely add that I take pleasure in admitting the advantages and satisfaction to be derived from a classical education, supplemented as far as possible with a knowledge of modern language, in which I should certainly include French, German and Spanish. My experience teaches me that the student should pursue his studies as early as possible, for unless he denies himself the opportunities offered for recreation and social intercourse, he will find that owing to the demands upon his energy required in his regular employment, he will find less and less opportunity to study. My early telegraphic work, followed by years of editorial experience, and accompanied at all times with reading of the best English literature, has forced upon me what little knowledge of our language I possess, and at the same time taught me that a more thorough general education would have established a more, satisfactory foundation, which I would urgently advise young men to obtain, and the neglect of which is to-day inexcusable.

MR. RAYMOND:—I think the paper has had an injustice done it. These gentlemen apparently assume that as soon as men graduate from college that all study ceases. I propose to drop during the college course those studies that will be taken up by the students themselves later, such as literature and history. A man can read history without a trained professor to assist him. One who has come out of college and has studied for four years is not going to stop as soon as he graduates. It would undoubtedly be interesting to study astronomy during the college course, but we must agree there is no time to take it up. Many of us since leaving college, may, however, have studied it quite thoroughly. I repeat, why not drop the studies that can easily be taken up after graduation and concentrate on those most urgently needed in our profession and in a large number of cases not properly taken up during the college course.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF PAPER BY M. LEBLANC.]

The result of M. Leblanc's paper can be obtained in a very simple way by directly considering the case of a transmission line having no ohmic resistance but only distributed capacity and self-induction. I will briefly outline how to obtain this result, leaving to a special paper the highly interesting subject of the phenomena of long transmission lines treated in an elementary way.

The differential equation for a long transmission line having distributed capacity and distributed self-induction is readily obtained from our figure. Let C be the mutual capacity per unit length, and L the inductance per unit length of the two wires, then the charging current per unit length is

$$i = 2 \pi n C v \tag{1}$$

where v is the potential between the wires. Setting $2 \pi n C = a$, for the sake of simplicity, we have

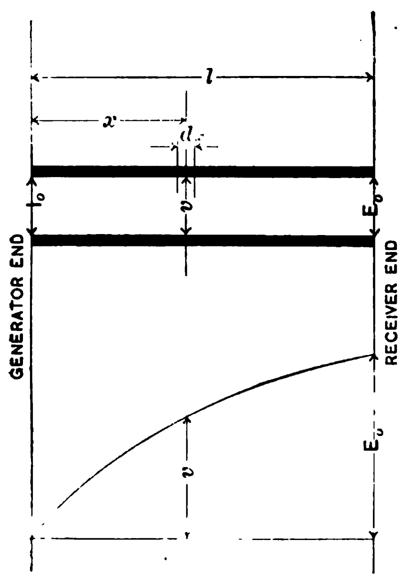

FIG 1.

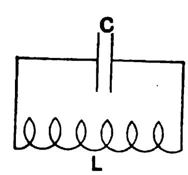

FIG. 2.

$$i = a v \tag{2}$$

The e.m.f. of self-induction is equal to

$$e = 2 \pi n L i \tag{3}$$

Again, setting $2 \pi n L = b$, we obtain

$$e = b i \tag{4}$$

Let us investigate the distribution of potential along the line on the supposition that the potential at the generating end is zero, then the distribution of potential thus obtained will be identical with the distribution for the fundamental of the natural vibration of the line.

We have for the charging current in the element $d\,x$.

$$di = a\,v\,d\,x \tag{5}$$

The inductive drop in the line is

$$dv = -\,b\,\imath\,d\,x \tag{6}$$

Hence, by differentiating (6) and substituting in (5) we obtain,

$$\frac{d^2 v}{d\,x^2} = -\,ab\,v \tag{7}$$

The solution of this equation is

$v = A \sin \kappa\,x + B \cos \kappa\,x$, for by differentiating

$$\frac{dv}{dx} = \kappa\,A \cos \kappa\,x - \kappa\,B \sin \kappa\,x$$

$$\frac{d^2 v}{d\,x^2} = -\,\kappa^2 A \sin \kappa\,x - \kappa^2 B \cos \kappa\,x$$

$$\frac{d^2 v}{d\,x^2} = -\,\kappa^2 v$$

Therefore, $\kappa^2 = ab$, and $\kappa = \sqrt{ab}$ (8)

For $x = 0, v = 0$, by our assumption, hence

$$A \sin \kappa\,x = -\,B \cos \kappa\,x$$

$$B = 0$$

Therefore,

$$v = A \sin \kappa\,x$$

For $x = l, v = E_0$, hence

$$E_0 = A$$

The potential at different points of the line is thus given by the equation,

$$v = E_0 \sin \kappa\,x \tag{8}$$

We obtain the maximum value of v for

$$\sin \kappa\,x = 1,$$

and, therefore, the most dangerous case exists for a line whose length is such that

$$\kappa l = \frac{\pi}{2}$$

or, substituting for κ its value $\sqrt{ab} = 2\pi n \sqrt{LC}$, we obtain

$$l = \frac{1}{4 n \sqrt{LC}} \tag{9}$$

Now, let us see what relation the length of the line thus determined has to the wave-length. It can easily be proved that the velocity of an electro-magnetic disturbance is given by

$$V = \frac{1}{\sqrt{LC}} \tag{10}$$

L and C being the inductance and capacity per unit length of the line in electro-magnetic measure.

Let λ be the wave-length, then we have

$$\lambda = \frac{V}{n} = \frac{1}{n\sqrt{LC}} \tag{11}$$

and substituting in (9)

$$l = \frac{\lambda}{4} \tag{12}$$

which is M. Leblanc's result arrived at in a strictly correct but simple manner.

I need hardly remark that from equation (8) follows that if κl is equal to $3\pi/2$, $5\pi/2$, $7\pi/2$, etc., a dangerous state is obtained.

From (9) follows that the fundamental of the natural frequency of the line oscillation is

$$n = \frac{1}{4 l \sqrt{LC}} \tag{13}$$

It is interesting to compare this result with that of a condenser and an inductance connected in series. The natural frequency of such a system (Fig. 2) can easily be obtained by the consideration that the potential difference between the condenser plates must be equal and opposite to that at the terminals of the inductance, hence

$$2\pi n L i = \frac{i}{2\pi n C}$$

From this follows:

$$n = \frac{1}{2\pi\sqrt{LC}} \qquad (14)$$

The discharge frequency of a long line with distributed capacity and self-induction is therefore greater than if the capacity and self-induction were concentrated as in Fig. 2.

The subject is treated by Dr. Bedell and Dr. Crehore, and by Mr. Steinmetz, and my remarks are made with the sole purpose of showing a short cut to the known results.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF MR. STEINMETZ'S PAPER ON THE "THEORY OF THE SYNCHRONOUS MOTOR."

Mr. Steinmetz calls the quantity $\frac{1}{2} m v^2$ by the name of "mechanical momentum," but since the time of Newton the term "momentum" has been used to designate the product $m v$, and we speak of the "conservation of momentum," and of the "conservation of angular momentum," meaning thereby the conservation of the product $m v$, as, for instance, in the case of impact. Since the formulation of the principle of the "conservation of energy," we have been accustomed to call the quantity $\frac{1}{2} m v^2$ the "kinetic energy" of the body in motion, and we should like to ask why Mr. Steinmetz deems it necessary to change, without explanation, a nomenclature which has been used by Helmholtz, Kelvin, Maxwell, Rayleigh and others.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY MR. CALVERT TOWNLEY IN DISCUSSION OF MR. A. H. ARMSTRONG'S PAPER, PAGE 809.]

I have read with much interest Mr. Armstrong's account of his various investigations, which involve and represent an enormous mass of painstaking mathematical calculations. His graphic representations of the results obtained are clear and concise, and will furnish material for much contemplation and study to any one interested in following out the possibilities involved by changing the numerous railway motor variables between widely separated limits.

His individual conclusions given as interpreting the various curves plotted are clear and well stated, but there is one general conclusion not deduced directly from the calculations which does not seem to me proved, and with which I am unable to entirely agree. Mr. Armstrong states:

"As a result of considerable investigation along these lines, the writer has not arrived at any commercial rating of a railway motor which serves its purpose better than the one-hour test now universally used. Admitting that such a test does not give the comparative size of different motors, it does serve the purpose of largely determining its commutating qualities and possesses the advantage of being commercial. Unless a rating can be proposed which will indicate accurately the relative size of motors, the present method of one-hour rating possesses advantages which would hardly warrant its being superseded."

Summing up briefly, the plotted results of the calculations show that there are some thirteen or more variables which affect the service capacity of a motor, that there is no short-cut method of rating a motor which takes into account all these variables, the inference being, therefore, that neglecting so to do is likely to lead to fatally erroneous conclusions. In the face of this set of conditions it is not clear to me what can justify the one-hour horse-power basis of rating motors which takes account of practically none of these variables. The advantages of the one-hour horse-power rating of motors are stated as follows:

" It does determine the mechanical qualities of the motor, as the one-hour test is generally very severe, and it also affords a means of observing commutation at the maximum current for which the motor will probably be called upon in service operation."

It is not clear to me what is meant by the " mechanical qualities " of the motor. This term cannot refer to the mechanical strength of the various parts of the motor, as the mechanical strains in a shop test of this nature are of course very light compared to the strains of service. The fact that a motor, resting on a stand in the shop, would take a certain amount of current for an hour, would hardly be held as any measure of its mechanical strength for its service on a road.

With reference to commutation, the comparison is hardly less decisive, as a modern commercial motor which did not at least commutate well on towards twice the current represented by its one-hour horse-power rating would hardly find much favor. There are two other reasons, not given in the paper under discussion, but sometimes advanced for the retention of the one-hour horse-power rating; first, that it is an established basis of comparison broadly known and used by railway men, and second, that the use of the term horse-power affords the advantage of a well-understood unit which is comprehensible alike to engineers and laymen. The first of these reasons is sound so far as it goes, but the same reason is always offered against any change in standards or nomenclature, and is scarcely sufficient for adhering to a method otherwise undesirable. The second reason has always appeared to me an argument against itself; *i.e.*, that the very use of the word " horse-power " as applied to a one-hour rating is misleading, in view of the fact that this term is broadly associated with the capacity of apparatus in continuous service. I well remember the strongly expressed disappointment and disgust of a prominent railway official who had been talking about the "horse-power " of railway motors, when he learned that the term meant capacity for one hour only, whereas he operated his lines twenty-four hours a day. If there is a good reason for adhering to the term "horse-power," it might better be applied to a rating corresponding to the duty which the motor would perform continuously.

In the light of all of the foregoing, a plea for the retention of the one-hour horse-power rating would seem to ask that as we cannot get a short-cut rating which will express with absolute theoretical accuracy all of the comparative features of two or more motors, let us use one which is as inaccurate as possible.

It is undoubtedly true that the increase in maximum and in schedule speeds, and also in the weight and amount of heavy traffic, which has been perhaps the most prominent feature of recent developments in electric traction, tends to aggravate the inaccuracies of short-cut comparison pointed out in this paper, and no one will gainsay the desirability of determining the adaptability of any particular motor to the service requirements for any particular installation with all the accuracy that is practicable, and is justified by the magnitude of the enterprise. In recognizing these facts, however, we should not forget that a very large proportion of the money which is invested in railway motors is by roads operating equipments of small or moderate capacity, operated at low or moderate speeds. For such roads it is frequently, one might almost say, generally impracticable to determine within accurate limits the service conditions described by this paper as necessary for the proper comparison of motors. It would, therefore, seem reasonable to determine within what limits a conclusion based on some short-cut method is likely to err, and in our methods to allow such a margin as will minimize the chances of any serious misfits It will hardly be disputed that if we cannot be absolutely accurate we should be as accurate as we can, and I for one should regard it as unfortunate should this INSTITUTE appear to the public committed to the statement that it is ordinarily impracticable to select a railway motor suitable to average service conditions without making a somewhat intricate comparison based on service data which it is impossible to obtain.

In this connection, the method of rating and comparing the service capacities of motors as proposed by Mr. N. W. Storer in articles entitled "The Capacity and Rating of Railway Motors," printed in the November 2, 1901, and January 5, 1902, issues of the *Street Railway Journal*, appeals to me as coming much nearer a useful method than the one-hour horse-power rating. The writer has had occasion to check the type of motor indicated by this method as best, with that shown most desirable by more intricate calculations obtained at considerable pains from service observations. In every case the motor selected by the Storer method has been a safe motor for the work, and very close in its characteristics to the calculated service conditions. On the other hand, instances are not lacking where selection on the basis of horse-power rating have produced results which were far from commutator. This result is secured in the motors built under the Johnson patents, as will be shown later from the result of tests. No essential difference exists between the special motor herein described and those of ordinary design, except in the construction of the pole piece which is made hollow, and within which is a solid cylinder of soft iron, radially adjustable. When adjusted to its innermost position, this cylinder or "plunger," as it is called, extends through the inner end of the pole piece, thus form-

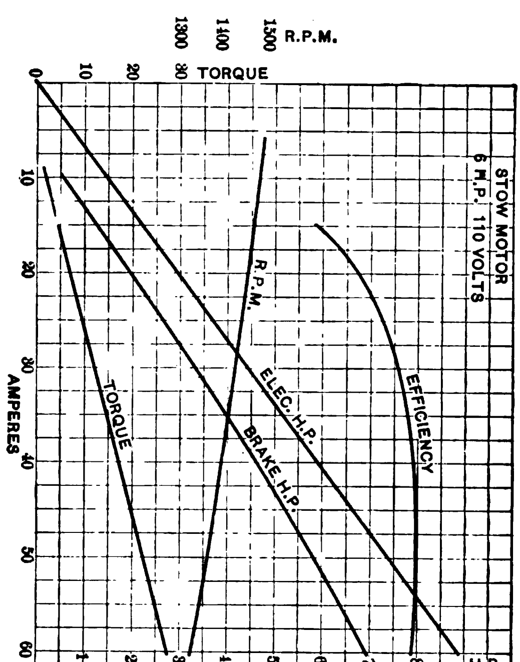

Fig. 8.

ing a portion of the polar surface, and as its cross section is much greater and its permeability higher than the inductive section of the pole piece, it carries the larger portion of the flux.

With the plunger in this position, the magnetic circuit is most complete and of minimum reluctance, and, since the m.m.f. of the field coil is constant, the volume of magnetic flux becomes a maximum and the speed minimum. When the plunger reaches the limit of its outward movement the reluctance of the magnetic circiut and hence the speed becomes maximum. Fig. 2 is a full view of the pole piece properly secured in the magnetic yoke, while Fig. 3 is a corresponding sectional view showing the inner construction.

As shown by Fig. 2, two opposite sides of the pole piece are cut away, leaving the sides solid over the pole tips. From Figs. 2 and 3 it will be seen that when the plunger occupies its outermost position the entire flux must reach the armature by way of the pole tips, thus affording the fringe at the pole tips necessary for sparkless commutation. Fig. 4 is a sectional plan view of the pole piece with plunger removed, the section being taken on the line x, x, Fig. 2. This view shows the two opposite sections through which the flux is conveyed down to the pole tips when the plunger is withdrawn. The sectional view, Fig. 5, is taken at right angles from the position shown in Fig. 3, the plunger being removed.

The object of the tapered lugs shown at the sides of the pole piece in Fig. 5 is to divert a portion of the flux from the plunger, as it is being withdrawn, and being connected integrally with the two opposite sides of the pole piece, these lugs also serve to strengthen the pole piece mechanically.

From the foregoing it will be seen that the operation of the special form of pole piece shown and described herein, is to force a gradually increasing proportion of the total magnetism down to the pole tips, the entire flux being delivered directly over the pole tips when the plunger is raised to its highest position.

In order to demonstrate that the desired results were actually secured with this special form of pole piece, the writer has measured the flux distribution at the pole faces of the various motors by the statical method proposed by Mordey.

Fig. 6 shows the relative distribution of magnetism half way around the armature of the 4 pole 6 h.p. Johnson motor. In this test a 500-turn exploring coil embracing two adjacent teeth was connected to the low reading terminals of a Weston voltmeter, and the throw of the needle observed on suddenly turning off the normal field current.

Observations were made at 49 equidistant points along the polar circumference, the diagram, Fig. 6, being plotted from the readings thus obtained. Two sets of readings were taken.

The outer curve, No. 1, was plotted from the first set of readings, and indicates the distribution when the plungers occupy their innermost positions, that is to say, when the total flux is maximum.

To obtain the inner curve, No. 2, the field strength was reduced to minimum by withdrawing the plungers from the armature as far as possible; the same exciting current was interrupted at the same speed; and the exploring coil made to occupy precisely the same positions within the field as in the first set of readings.

It is thus possible from these two curves to obtain a comparison of the flux distribution under the conditions of maximum and minimum field strength. Curve 1 resembles closely the curve of distribution which might be taken by exploring the field of any direct current motor of ordinary design.

The peaks in Curve 2 indicate a relatively strong magnetic field adjacent to each of the pole tips, while the depression between the peaks is caused by the withdrawal of the central portion of the pole face. In Fig. 6 the distance between adjacent vertical lines represents the width of two commutator bars. To secure non-sparking at all speeds in this machine it is found necessary to give the brushes a permanent backward "lead" from the neutral point of one and a quarter segments, this lead being indicated by the two circles above and below the horizontal axis.

It will be noticed that with a fixed lead of the brushes the strength of the commutating field is different under the conditions of minimum and maximum speed. In fact, it has been found that the machine operates sparklessly at the lowest speed by giving the brushes a lead of only one segment and at the highest speed by giving a lead of one and a half segments. If the brushes be given a permanent lead of one and a quarter segments, the machine carries its load sparklessly both at the lowest and at the highest speed.

From the manner in which Curves 1 and 2 were obtained, they do not accurately indicate the flux distribution when armature reaction is present. It might be supposed that when the field strength was weakest the armature reaction would so distort the field as to necessitate a greater displacement of the brushes from the neutral point than is required when the field strength is maximum. Such a condition is, however, avoided, owing to the particularly fortunate circumstance that as the field is weakened by withdrawing the plungers, an increasing reluctance is interposed in the path of the armature reaction, until when the plungers are fully withdrawn the cross magnetizing effect is reduced to a minimum from want of a conducting path through which to act. These motors are not the first machines in which the pole pieces have been provided with radial air spaces for the purpose of reducing the effect of armature reaction.

In the pole pieces of some of their multi-polar generators, about a dozen years ago, the Thomson-Houston Electric Co. made use of a wide radial slot, which practically divided the pole pieces in two equal parts, the purposes of this radial slot being to secure a more uniform distribution of flux over the surface of the pole face; to maintain a magnetic fringe at the trailing pole tip of sufficeint intensity to insure sparkless commutation; and to diminish the cross magnetizing effect of armature reaction.

The value of this central radial opening in the pole piece would seem to be established from the fact that since its introduction, other companies have adopted a similar practice, and with apparently good success.

In regard to the efficiency of the machines herein described, it is clear that there is no resaon why these machines, operating at minimum speed, should be less efficient than any other motor of similar speed and capacity; and with an increase in speed of 125 per cent., these machines carry their full load with an efficiency about 4 per cent. less at maximum than at minimum speed, the reduction in efficiency being due to increased friction and iron losses at the high speed. As the speed control is accomplished without the use of resistance either in the field or armature circuit, the C^2R losses for a given load are practically uneffected by the speed.

Figs. 7 and 8, respectively, show the action of the 6 h.p. motor when operated at minimum and maximum speed, these curves showing the relation of current input to the speed, torque and efficiency.

Comparing first the speed at no load, we find the minimum speed to be 660 and the maximum 1,475, thus covering a range of 123 per cent. variation; and, as screw threaded means are employed for simultaneously adjusting the plungers, it is evident that any imaginable speed between the limits specified may be obtained.

Operated at minimum speed the full load of approximately 50 amps. shows the self-regulation of speed to be within 6 per cent.; while under high speed conditions, the curve indicates that a similar load reduces the speed a little less than 8 per cent. In larger machines the self-regulation is closer than on this 6 h.p. size.

As these motors are designed to develop their full rated h.p.

at any speed within their range, it follows that for a given load the torque must vary inversely as the speed. In other words, in a machine whose maximum speed is twice the minimum, the full load torque at maximum speed will be one-half as great as at the minimum.

Referring to Figs. 7 and 8, we find that operated at maximum speed the efficiency at full load of 6 h.p. is 79 per cent., while at minimum speed the same h.p. is developed at an efficiency of 83.5 per cent., showing a difference in efficiency at full load of only 4½ per cent. This loss of efficiency due to speed variation seems negligible when compared with the loss of efficiency in a variable speed equipment of equal range whose speed is varied by resistance in series with the armature.

Where the range of speed is sufficient, these motors also present the advantage of simplicity over those methods of speed control in which a double wound armature is employed or in which a plurality of auxiliary machines or line voltages is required.

It will be seen that the motor herein described differs from all others in that with constant potential at the terminals, it carries its full rated load at any imaginable speed within the limits of 125 per cent. variation, with an efficiency practically independent of the speed at which it is operated.

It would be a mistake to suppose that this comparatively wide variation of speed is due to the employment of high air-gap density at minimum speed or to low armature reaction by which the weight and cost of the machines would be increased, and as a matter of fact these machines conform very closely to the practice of the leading manufacturers, in the matters of armature reaction and air gap densities.

In these machines the minimum speeds have been chosen much lower than usual for corresponding sizes, so that, with an increase of 100 to 150 per cent. of normal, the peripheral speed shall not greatly exceed that obtained in the moderate or medium speed machines of other manufacturers.

[For discussion of this paper see pages 1142-3.]

Discussion.

President Steinmetz:—Gentlemen, you have listened to Mr. Packard's paper and discussion is now in order. As you see, the paper describes a method of providing speed control over a very wide range in motors. I understand the author has been largely instrumental in developing this method of controlling speed, and I congratulate him on his success. Discussion is now in order.

Prof. Esty:—The last speaker has referred to two methods previously used to control speed, one due to Mr. Diehl and one to Mr. Edison. I would like to ask if there was not another method employed years ago by the Crocker-Wheeler Company, using hinged pole-pieces, the distance of which from the armature could be varied at will. My impression is that there was such a device, and not hearing it mentioned, I wondered if it had not been overlooked by the author.

Mr. Packard:—I have corresponded widely to find out the names of patentees and also to read the patents which have been issued along this line, and have not succeeded in finding other patents than those of Diehl and Edison, although I am inclined to think that a modified form of machine from that described in the Diehl patent has already been used.

Mr. Thomas:—I should like to ask for information as to experience in the limits of size and speed in this type of machine. For instance, is it possible commercially and mechanically to construct a very low-speed motor of considerable size on this principle; assuming, for instance, the highest speeds, that would be within the range of what is ordinarily understood as low-speed motors.

President Steinmetz:—I am sorry that our friend Mr. Dunn is not here to participate in the discussion of this problem, with which he is specially familiar. I may say that the problem of varying the speed of a continuous-current motor has occupied the minds of electricians for very many years, and has been very carefully studied. There are two ways of varying the speed of a continuous motor, varying the e.m.f. on the armature, or varying the field strength. The first has been developed by our worthy friend, Mr. Leonard. The latter is used to a considerable extent, and is usually accomplished by varying the exciting current. The objection to speed control by variation of the field excitation is the limited range available, since with a decrease of field magneto-motive force the distortion due to armature reaction increases. A somewhat better method appears to be a decrease of field by increase of the magnetic reluctance by means of lengthening the air-gap. While the distortion is not thus increased, the commutating field is decreased and commutation thereby impaired. Mr. Packard's paper shows a further method, by which, without varying the field m.m.f. nor the commutating field, that is, without affecting armature reaction and commutation, the field strength is varied over a wide range.

Mr. Raymond:—I would like to inquire how large a machine has ever been built on this principle.

Mr. Packard:—The development of the multipolar form of machine built on these lines is comparatively recent, and only two machines have thus far been built—a 6 h.p. size, the results of which are shown by the diagrams, and an 8 h.p. size.

Mr. Raymond:—I would like to ascertain the voltage of those two machines.

Mr. Packard:—As noted on the diagrams, the 6 h.p. was wound for 110 volts; while the 8 h.p. was wound for 220 volts.

Delivered at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington Mass. June 21st, 1902

PRESIDENTIAL ADDRESS.

BY CHARLES P. STEINMETZ.

GENTLEMEN:—With to-day's meeting ends the first INSTITUTE year in the new century, and it may then be appropriate to look back into the work achieved and forward into the future.

At the entrance of the 19th century we see empirical science struggling for recognition against metaphysical speculation. At the entrance of the 20th century metaphysics has practically ceased to be considered, and empirical science is universally acknowledged as the source of all human progress. In gradual advance from success to success this victory has been won. Empirical science can now expand without any restraint. But with the removal of the opposition of a hostile philosophy, has been removed also the searching criticism into the correctness of the results, the methods and the theories propounded by empirical science, and thereby the absolute safety which characterized the work of the earlier period. Herein lies the greatest danger to the unbroken progress of science.

Facts, whether observed incidentally or intentionally by experiment, are the foundation of science. But the mass of facts has accumulated so as to be beyond comprehension, and we are forced to work with the conclusions from the facts, the empirical rule, theory and hypothesis, and have become so used thereto that gradually the dividing line between the theory and the underlying facts has become blurred, so that we attribute to the theory the same certainty as the facts on which it is based. But, however well a theory represents the fact and proves its value in successful application, it unavoidably contains besides the facts on which it is founded, foreign elements, mainly the personal equation of its originator and the personal equation of its times. When building upon theories, the danger exists that instead of building upon the facts represented by the theory, we may build upon the personal equation of the time, without realizing the unsafe foundation of our structure.

The reverence for facts as the foundation of science has been extended to the theories based upon them. But when by building theories upon theories, conclusions are derived which cease to be intelligible, it appears time to search into the foundations of the structure, and to investigate how far the facts really warrant the conclusions If we are told of matter moving in a vacuum tube with velocity comparable with that of light, of small chips breaking off atoms, of free atoms of chlorine and sodium floating around in a salt solution charged with opposite electric charges, whatever that may be, of electricity being propagated not through the conductor, as we used to assume, but through the space surrounding it, etc., it is time to pause and try to understand.

In the gradual replacement of facts by the belief in theories more or less inadequately representing the facts, lies the chief danger to further scientific progress. Here is a field where splendid work in destructive criticism can and should be done by the younger generation, which, after leaving college with all the theoretical armament required, is not yet handicapped by personal relations with the men whose names are identified with the ruling theories.

Especially for our branch of electrical engineering, this is of fundamental importance, since all the success of our work depends upon the absolute safety of the foundations on which we build.

All future progress in science and engineering depends upon the young generation, and to ensure an unbroken advance it is of pre-eminent importance that the coming generation enters the field properly fitted for the work. Here the outlook appears to me by no means entirely encouraging.

It is not the object of the college or university to turn out full-fledged engineers who can handle any engineering problem of any magnitude. The available time is altogether too short for this, and a very great deal of practical experience is required which is not available to the educational institution. It is not necessary, either, and the college graduate is not expected to take immediate charge of engineering works of great magnitude. All the educational institution can do and should do is to fit the student to take up the practical work as efficiently as possible, and to give him *a thorough understanding of the fundamental principles of electrical engineering and allied sciences*, and *a good knowledge of the methods* of dealing with engineering problems. At present the average college course does not do this.

One of the reasons of the inefficiency of the present college course is the competition between colleges. By each college trying to teach more than any other, the quantity of material taught has gradually increased so that it is no longer possible to give a thorough understanding, and memorizing takes the place of understanding. Memorizing however, is an entirely useless waste of energy, since anything that is not perfectly understood, but merely memorized, will be forgotten in a short time if not continuously applied, and if continuously applied it would be remembered anyway. If of the amount of material in electrical engineering as well as other branches which the educational institution of to-day attempts to teach, one-half or more should be dropped altogether, and the rest taught so as to be fully understood, with special reference to general principles and methods, the product of the institution would be far superior and more successful in practical life. To be dropped, then, are all formulas, rules, etc., beyond the most simple ones, of the scope of the multiplication table, etc. When needed, formulas can be derived from the fundamental principles or looked up in the literature, and their memorizing is a mere waste of valuable time, useless since the memory cannot retain what the understanding is unable to reproduce from its premises. This, for instance, applies to the various formulas of electromagnetic induction, the equations of the transformer and other apparatus, and to theoretical investigations in general.

Still more than to electrical engineering this applies to the allied branches of science and engineering, of which the electrical engineer should have a fair understanding. Here anything beyond fundamental principles is objectionable. The electrical engineer should understand the principle of the steam engine, of the hydraulic turbine, should know why the spouting velocity and the peripheral speed of the water-wheel are related to each other theoretically, and how this relation is modified actually, but he should not memorize the mathematical theory of the turbine with its half-dozen unknown friction coefficients. He is not expected to design turbines, and if he did, his design would surely be a failure, but he is expected to understand the turbine, the steam engine, etc. The engineering graduate should know the principles of the strength of materials, the distribution of forces in the loaded beam, the reasons leading to the "I" beam, and to the triangle in bridge and roof construction, but time should not be wasted in calculating bridges or deducing elastic curves, etc.

In short, in electrical engineering, and still more in all allied branches, nothing beyond the general principles is needed for success, but the principles should be fully understood, and with the limited time at the disposition of the student, this cannot be done if time is wasted in memorizing things to be forgotten afterwards.

One objectionable feature of the instruction of most colleges is the step by step method. One subject is taken up, by application of sufficient time and energy pushed through, and then after passing an examination dropped to take up another subject. It is true that by steady application to one subject a great deal can be learned and splendid results derived in the examination papers, but all that is learned in this manner is just as rapidly forgotten. To understand a matter thoroughly, so as really to have a lasting benefit from it, and not merely make a good showing in examination papers, requires several years familiarity. Therefore, any subject, that is not kept up during the whole college course might just as well be dropped altogether and the time spent therein saved.

We hear that college graduates have no mastery of language, cannot express themselves logically, and it is therefore recommended that more time be devoted to literature and instruction in the English language. But as long as we do not teach logic, but have the English language taught by philologists, more or less of the character of the florid newspaper style, that is to write very many words on a very small subject, no useful results can be expected. Logic should be taught by a scientist, and the principle of English teaching to engineers should be to enable them to explain a subject intelligently and logically, with as few words as possible. That is, Faraday's researches, and not the product of the successful novel writer should be the example aimed at.

The combination of text-book and home work offers a splendid chance for incompetent instructors to make an elegant showing in examination papers, and turn out a very inferior grade of men, who sometimes do not even know what real understanding means. Free lectures on subjects which the instructor himself thoroughly understands (which is by no means always the case now) make it possible to direct the course so that the student's understanding follows it, and in this case home work becomes superfluous, except in connection with the laboratory. Reviewing the lectures and filling out the gaps due to absence, etc., appears to me the only legitimate requirement on the student's time outside the lecture room.

The present method of examination, which consists in expecting the student to answer ten questions or so within a few hours, is faulty. It shows what the student has memorized, but not how far he understands it. Furthermore, the brilliant student who usually answers nine questions out of ten correctly, and would have answered the last if he had not made a slight mistake, displaced a decimal point or so, in practical life may be utterly useless, since while doing very rapid work, his work is not reliable, while a slow man who, however, can absolutely rely on the correctness of his work, will be very successful in practice while hardly passing the college examination.

What, then, should an ideal electrical engineering course contain?

Of mathematics, plain and some solid geometry, arithmetic, and a good knowledge of algebra. Plain trigonometry—no spherical trigonometry required—and a thorough understanding of analytical geometry and of calculus, but no memorizing of integral formulas, etc.; they can always be looked up in a book when needed.

A thorough knowledge of general physics, especially of the law of conservation of energy, which I am sorry to say is not yet an integral part of our thinking, and of chemistry, especially theoretical chemistry and the chemical laboratory, in the latter freely using tables, etc.

The electrical laboratory work should be taken up right at the beginning. Even before taking up the theory of apparatus, the theoretical investigation of alternating currents, self-induction, transformers, etc., the student should have met these phenomena and handled the apparatus in the laboratory. Only after seeing the effects of self-induction, for instance, on the alternating current circuit in the laboratory, will the theory of self-induction have any meaning or make an impression on the student. What the student has seen practically in the laboratory he will then take up in the theoretical course, and understand it, he will learn to calculate and control, and afterwards, going back once more to the laboratory, to apply it. It is here that the average college graduate is inferior to the practical man, and in spite of his handicap regarding theoretical knowledge, the latter frequently pushes ahead of the college graduate because of his superior understanding of the phenomena, based on his familiarity with them.

Design of electrical apparatus is of very secondary utility and rather objectionable, with the exception perhaps of some very simple apparatus. The considerations on which designs are based in the engineering departments of the manufacturing companies, and especially the very great extent to which judgment enters into the work of the designing engineer, makes the successful teaching of designing impossible to the college. Far better is the reverse operation, the analytical investigation of existing apparatus, and more instructive to the student. That is, to derive from existing first class apparatus by measurement and test, the constants of the apparatus, and to calculate these constants and compare them with tests. Besides, a very small percentage of the college graduates enter the field of designing, but most of them will have to handle apparatus, and it is therefore very much more important to be familiar with the completed apparatus in all its characteristic features, in normal and in abnormal operation, than to be able to design it.

The preceding naturally can be a short outline only of the work which I consider appropriate to an electrical engineering course, but I believe the general principles of the course can be understood from it. They are, to give the student all the ground work required to be successful in future practice, but not the impossible aim of giving him a complete education as a practical engineer.

A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 21st, 1902.

CONCERNING UNIFORMITY IN THE ELECTRICAL ENGINEERING COURSES IN THE UNITED STATES.

BY SAMUEL SHELDON.

Technical schools and other higher educational institutions, considered as business corporations, are of necessity conducted in a unique manner. Like ordinary business concerns they are sellers of goods, namely, knowledge and educational wares, the students being the customers and paying in money, in time, or in both. The educational institution is in the peculiar position of being able to dictate the things which the customers must purchase, and the customers, furthermore, are not in a position to determine the quality and genuineness of the goods delivered. The condition is modified somewhat by extensive use of the elective system. Because of this condition of affairs, it is of great importance that the professors, the directors, or those who are responsible for the curricula should be well-informed and broad-minded men, be possessed of good judgment, and be free from personal motives or bias. The selection of the curricula of the technical courses in our country has unquestionably been influenced by competition in the form of friendly rivalry, and by the information given in the papers, the discussions and the personal intercourse of the various professional societies, especially of the Society for the Promotion of Engineering Education.

The determination of a curriculum does not, however, lie wholly in the hands of the officers of the educational institutions. The history of our technical schools from the foundation of the first one at Troy in 1824 to the present, with its problem of ever-increasing numbers in the laboratory, shows an influence on the part of the student body. This body has distinctly utilitarian purposes. The average student attends a technical school in order to get that which will enable him to earn a living. He desires a better quality of living than he could hope to get otherwise, and he wishes to get it as soon as possible. Such haste may not be for his good, but the mental attitude exists and its existence must be recognized. Probably every instructor has conversed with undergraduates who wished to discontinue their studies and take up,to their minds, lucrative positions,which had suddenly become available. A lack of recognition on the part of classical colleges of this impatience of the average student, may account for their apparent conservatism in the past toward technical instruction. At any rate, to its recognition is due, to no small extent, the rapid growth of the technical institutions.

A course in electrical engineering, to meet the desires of its patrons, should be laid out with a view to securing the best possible positions for its graduates. The student body is made up of some brilliant students, some dull ones, and many of medium ability. The course should be adapted to the wants of the last class. The brilliant man will lead his fellow students and will always look out for himself. The dull student will lag behind, but will be much benefited by the struggle.

The average electrical graduate takes a subordinate position with people engaged in the construction, the sale, the erection, or the operation of electrical machinery. The initial rapidity of his advancement depends upon his technical education,and could be made a maximum by a thorough understanding between the employer and the educator. His ultimate position seems to be dependent almost entirely upon himself and very little directly upon any special feature in his educational training. Inquiry of employers reveals the fact that there is considerable dissatisfaction with graduates, irrespective of whence they come; that employers prefer to do their own special training and to supply the graduate with his special facts; and that employers consider that the average graduate lacks something, and this something is variously and often vaguely defined as: "initiative of thought and action," "breadth of training," "breadth of thought," "training in fundamental principles," "horse-sense," etc.

By reference to the catalogues of a large number of institutions and to Caldwell's admirable comparative table of electrical engineering courses[1] the following table has been made, which shows the maximum, the minimum and the average time devoted to various subjects in various institutions. The time unit is one

1. Proc. Soc. Promotion Engineering Education, VII, p. 128.

hour per week per academic year. This equals about 36 actual hours of lecture, of recitation, or of quiz, or 72 actual hours in the drawing-room, the laboratory or the shop.

TIME DEVOTED TO SUBJECTS.

Subject	Time in any one institution.		Average time in all institutions.
	Minimum.	Maximum.	
Mathematics	5	11	9.2
Drawing	3	10	6.2
Physics and Chemistry	7	25	14.0
English	0	11.3	4.5
French and German	0	10	4.9
Shop-work	0	21	7.5
Electrical Engineering	9.5	23.8	16.5
Other Engineering	7.7	23.2	15.8
Thesis and Elective	0	7.1	0.3

There is considerable uniformity of requirements in mathematics, in physics and in chemistry. Apparent differences of time in the above table are compensated by differences of entrance requirements. The time spent on other subjects varies greatly in different institutions. As an instance, electrical engineering students at Cornell spend ten times as much time on shop-work as those in the Massachusetts Institute of Technology. Such differences in the curricula of institutions of unquestionably high standing suggest prodigality in the expenditure of a student's time and suggest the possibility of obtaining much higher teaching efficiency by the adoption of uniform curricula, uniform not only as to the time to be devoted to the different subjects, but also as to the topics to be treated in that time and as to the manner of their treatment. The instruction given in preparatory schools has been very much improved by the standardization of their courses. The time thus saved could be devoted to subjects which would tend to produce the results which employers of graduates now consider as wanting. Perhaps that which the present graduate lacks is the broad-mindedness associated with graduates from classical and art courses and which, as a whole, is considered as an indication of a liberal education.

The results which the liberal educator aims to achieve in his student are the following:

(1) To discipline his mind so as to create a power for coördinate thought.

(2) To impart to him a knowledge of facts.

(3) To develop a power of expression in language or in action.

(4) To discipline his emotional sympathy so as to develop an æsthetic taste.

(5) To discipline his moral faculty.

The first three are also the aims of a technical education and are accomplished through the study and treatment of special facts lying in a very narrow field. The facts employed by the liberal educator are drawn from the whole domain of human knowledge and are purposely chosen so as to give the student a superficial and general survey of human achievement. A knowledge is imparted of man's relations with the material universe by facts drawn from the natural sciences; with his thinking self or soul by a study of psychology, of logic and of mathematics; with his fellow man of the present from a study of ethics, of economics, of politics and of sociology; with his fellow man of the past, from a study of history; with the universe as a whole, from a study of philosophy; and with God, from a study of religious ideals and problems.

This curriculum has a two-fold purpose; first, to assist the student in choosing a calling which will be congenial and suited to his abilities, and secondly to develop roundly all his faculties, so that he may properly use his senses for pleasure, his intellect for truth, his emotions and æsthetic nature for beauty, and his will for right and duty.

The average graduate from a liberal course possesses a breadth of culture which is easily distinguished as being in excess of that possessed by the average technical graduate. The two courses have so many immediate purposes in common that this difference might be largely eradicated by a single carefully planned course of lectures.

It is objected that a uniformity of curriculum leaves no opportunity for the exercise of the individuality of the professor. A man who is strong in one branch, it is urged, should devote more time to that branch than to others. It seems as though the place for individuality were in the university, and, if exercised in the technical institutions or departments, it should be combined with special advantages of material equipment in the same branch or with special conditions due to the location of the institution and its environment. The legitimate ultimate purposes of a technical institution are so utilitarian and different from those of the liberal institutions that the extensive use of electives *on the part of professors*, which is so admirably adapted to ordinary college requirements, is detrimental to the best interests of the technical student and is wasteful of his time.

A papr presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 21st, 1902.

ELECTRICAL ENGINEERING COURSES AT COLLEGE AND THE EDUCATION OF THE ELECTRICAL ENGINEER.

BY WILLIAM ESTY.

I wish to preface my remarks on electrical engineering education by thanking President Steinmetz for his thoughtfulness and broad-minded policy in giving to the teachers of electrical engineering this opportunity for discussing with those eminent in the profession their ideas on how electrical engineering should be taught. By providing this clearing-house for the exchange of ideas, the intimate relations between the engineer, the manufacturer and the college will be revealed, and a better understanding of the requirements to be met by our technical graduates in commercial work, will result. In these ways and others, the cause of education will be greatly benefited.

THE NEW SITUATION.

In the pioneer days of the older branches of engineering, there was required, except for elementary mathematics, but little scientific knowledge. In this stage, engineering was an art, not a science, and hence as in all the arts, the regular method of instruction was by apprenticeship. The pioneer engineers were all men of little education, but of considerable training in the school of experience.

This old régime has passed away, and a new situation has arisen with the growth of modern science. We have a rich inheritance of accumulated wisdom and experience, but he who would possess it must earn it by strenuous toil. For no one who has not mastered the sciences which his predecessors have developed can hope to attain success in engineering to-day. The common school education, enough for the pioneer, is no longer adequate. Experience has shown that the most direct road to the mastery of the sciences lies through the college. Other things being equal, a student can gain a better and broader education in less time by attending a first-class college than in any other way. I think we are all agreed on this point, and it is the recognition by the public of this fact that accounts for the marvellous increase in the number of students enrolled in our technical colleges. This number has more than trebled in the past decade, and is now over 10,000. There are more than fifty institutions in this country giving instruction in electrical engineering, and the students pursuing this course alone number over 2,500.

The Recognition of the New Situation by our Professional Schools.

In all professional schools there is a growing tendency to increase the requirements for admission and to raise the standards of graduation. Thus a few of our older and larger institutions have come within a few years to require in the applicants for admission to their law and medical schools, at least four years of college education.

As engineering has rightfully come in recent years to rank as one of the learned professions, it is worth while to ask why the long and severe preparation now so freely conceded to be necessary for the proper equipment of the lawyer and doctor, should not be deemed equally necessary for the engineer. There is hardly a thoughtful engineer who is willing to admit that his profession makes any less demand upon his powers or requires any less skill, perseverance or energy than the profession of law or medicine makes upon its followers. Why, then, should the preparation of the engineer for his life work be any shorter or less strenuous than that for law or medicine?

The Importance of the Study in College of History, Economics and Literature.

Besides the thorough grounding in the principles of the sciences of physics, mechanics, chemistry and mathematics, the well-trained engineer needs a broad elementary training in other departments of human knowledge. He should know something of history and economics, of language and literature, that he may correctly estimate the limitations and relative value of his own work and thought in comparison with the work and thought of other men. It is especially through the so-called culture studies and the broad outlines of general knowledge, serving to put a man in touch with all times and all men, that a broad outlook and wide sympathy can be acquired.

The Coming Education for the Engineer.

The ideal education for an engineer, and I use the word ideal meaning something that is to be, is a literary and scientific course of a general nature covering three or four years, followed by a special technical course extending over two or three additional years. Recognizing the undoubted advantages to the student and to the profession of both general and technical education, some of our colleges are encouraging this practice by making it possible for an earnest student to complete both courses in six years. Similarly, graduates of reputable literary and scientific institutions may secure a degree in engineering at some of our best technical schools within two years; and the tendency to regard an engineering course as post-graduate professional work is increasing, as is evidenced by the increasing number of graduates of literary colleges taking engineering studies.

The Compromise.

Granting, then, that a preliminary liberal college education is a good, if not a necessary, preparation for the electrical engineer to-day, it is of the utmost immediate importance to determine how we ought to organize our technical courses to produce the best results possible in the limited time of four years. The proper choice and sequence of the studies is a matter of great difficulty, for under present conditions we must satisfy the demand for both a fair general education and a technical training, all to be compressed within the short four years.

An examination of the catalogues of colleges giving four-year courses in electrical engineering will show the following divisions of time allotted to the different groups of studies in the electrical engineering course.

Culture studies (English, modern languages, etc.)	10%–20%
Indirect technical studies (mathematics, physics, drawing, shop, etc.)	30%–40%
Technical studies	50%–60%

The electrical engineering course at Lehigh University emphasizes the importance of culture studies to the extent of making them 18 per cent. of the total, giving 32 per cent. of the time to indirect technical studies, and 50 per cent. to professional subjects.

It is the common experience that it is impossible to teach culture subjects effectively in a course with decided technical tendencies. The student underestimates the value of the culture studies, and hence devotes most of his energies to the technical subjects. The disadvantage of this situation is two-fold. The student is apt to conceive a dislike for subjects studied in a half-hearted way, and he fails to secure a return commensurate with the time and effort devoted to these studies. This difficulty is a significant warning that our present practice of combining two radically different groups of studies in a single four-year course is fundamentally wrong.

Status of Electrical Engineering Courses Compared with Other Branches of Engineering.

With our older engineering courses, such as civil and mechanical engineering, educational materials and methods have become pretty well established and fairly uniform the country over. Long experience has demonstrated in general what studies are best to include in the curriculum, what the sequence of subjects should be, and there are excellent standard text-books to be had. In electrical engineering the case is quite different. To begin with, the profession of electrical engineering is a very recent one. Invention and industrial applications of electricity are growing with bewildering rapidity. Practice is changing radically day by day. Subjects like the long-distance transmission of power and most of the electro-chemical developments are scarcely ten years old. As a result of these unprecedented conditions, it is but natural that teachers of electrical engineering should be feeling their way, experimenting to find a solid foundation on which to build a substantial course for electrical engineers.

The question of text-books, especially those dealing with the practice of electrical engineering, is a serious one. A book can hardly emerge from the press before it is out of date. It seems, moreover, to be a common impression, at least as far as books on the practice of electrical engineering are concerned, that those who know most about the subject will not tell what they know, while those who do not know, frequently write the books. Hence, for the latest developments and current practice, teachers of electrical engineering have to depend mainly on the transactions of the engineering societies and other periodical literature.

Again, as to the amount and kind of published technical information, a radical difference is to be noted. In the journals of mechanical and civil engineering, appears full and detailed information on the latest designs of locomotives, machine tools, steam engines and boilers, bridges and other engineering works. In electrical engineering, on the contrary, very little detailed information about recent machines and apparatus is ever published. This state of affairs seems to be peculiar to America, for in Germany and other foreign countries the unwillingness to publish data and results of tests is not characteristic of manufacturers. I confess I am unable to account for this radical difference in custom prevailing between the electrical and other branches of engineering. Whatever the explanation of the difference, it is certain that in this regard the teacher of electrical engineering is severely handicapped in comparison with his colleagues in civil and mechanical engineering.

Commercial Aspect of Electrical Engineering.

A common complaint among practicing electrical engineers is that college graduates are not practical. This criticism is well founded, but it is a necessary and logical consequence of our scheme of education. When an employer engages the services of a man just graduated, he should not expect him to be exactly fitted by a college education for the practical work he is hired to do. What the employer should expect is a thorough grounding in principles, so that the young man will be able easily and quickly to master the details of his particular work and carry it on with success. The kind of technical education herein advocated aims not to make the graduate immediately successful in commercial life, but aims rather at ultimate success.

While we all admit that commercial conditions are always present in engineering, we would probably likewise admit the difficulty, if not the undesirability, of attempting to give formal instruction in purely commercial affairs. At the same time, teachers recognize, I think, that manufacturers and engineers are on the watch for technically trained men with business instincts. We likewise realize that the most successful technical graduates are those in close touch with commercial life. How, then, may we help to keep our engineering students in touch with current practice and affairs? Various ways are possible, each of which has its peculiar advantages.

(1) By familiarizing the student with the so-called trade

literature, including manufacturers' and dealers' catalogues. In this literature may be found examples of the latest and best designs, and often technical information of great educational value. To make these catalogues of the greatest benefit, there should be facilities for filing and preserving this useful material for ready reference.

(2) By securing from manufacturers drawings, photographs and samples of their product. Lantern slides made from photographs of the latest apparatus and electric plants, are an important aid to the teacher in keeping his students in touch with current practice.

(3) By visits of inspection to manufacturing establishments and electric lighting and power plants.

(4) By encouraging the student to engage in practical work during his summer vacations.

(5) By securing periodic lectures from men of affairs, or from specialists in certain lines. To see something of the personality of a man eminent in his profession, to be brought from the class room into an atmosphere of affairs and engineering realities, is to the student an inspiration. Would that more of our practicing engineers might realize the possibilities in doing this missionary work for our colleges.

Laboratory Work.

One of the most important advances in engineering education has been the introduction of the laboratory method of instruction. Many of our technical schools have a large and expensive equipment of apparatus the chief object of which is to aid the work of instruction. In the emphasis put on laboratory instruction, our American schools lead the world. But even with the equipment it is not easy to organize and plan a laboratory course that will always yield the best educational results. In some colleges, too many experiments are undertaken. With such, quantity rather than quality of work appears to count. In some cases, owing partly to the large number of students in proportion to instructors, and partly to save time, the galvanometers, bridges or dynamos are all connected and wired up in advance by the instructor. The exercise consists in having the students take certain readings and observations which they record in notebooks. These readings are then taken home and " worked up," and the results handed in. This mechanical procedure pretends to be laboratory work.

As an illustration of the other extreme, sometimes used in conducting laboratory work, take the actual case that came to my attention not long ago. It was the practice of a certain professor to assign in the laboratory a particular dynamo to a pair of students with the laconic remark, "go and find out all about that dynamo." The students thus turned loose in the laboratory tried to carry out their instructions, and with but little help, advice or direction, used to potter over that one dynamo for months at a time. Now of these two extremes in laboratory management, the latter is certainly the better. For what those students finally knew about that dynamo was considerable, and best of all, it was first-hand knowledge, the only true knowledge. The method, however, was at fault in this case in being overdone, since from lack of directed effort, the students wasted much valuable time.

Too great care cannot be taken lest laboratory work be over-directed or under-directed. The only satisfactory way is to divide a class into small sections, and devote much time, especially at the beginning of the work, to individual instruction. Handled aright, the student can be taught to think and act for himself. But without constant watchfulness and judicious direction, all the immense power for education possessed by the laboratory method may be entirely lost.

Perhaps the chief value of laboratory work is to give the student that critical. painstaking. conservative attitude of mind known as the scientific spirit. A student who from two or three hasty measurements is confident that he has discovered a new principle, has failed to acquire the scientific spirit. Faraday spent seven years of patient toil in the laboratory before he was able to announce the law of electro-magnetic induction, which seems simple enough to us.

Design as a Class-Room Subject.

There are doubtless many present who think that the teaching of electrical design should not be included in a college course for electrical engineers. I am very strongly of the opinion that such a course, if presented and developed in the proper way, may be made of great educational value. This conclusion is based on nine years of experience in teaching the subject to students, and is confirmed by the experience of graduates of several years' standing who have taken the work.

A course in electrical design gives occasion for the application of the abstract principles of electrical science to problems which approach laboratory exercises in their character of reality. Such applications give to theoretical study an effectiveness not to be reached in any other way.

According to my practice electrical designing is begun at the commencement of senior year, and the time usually devoted to it is from four to six hours per week throughout the year. The course includes a study of the materials of electrical engineering, and a detailed study and calculation of electro-magnetic mechanisms, dynamo-electric machinery, and transformers. Work at the drawing board is reduced to a minimum.

Dynamo designing is both an art and a science, according to the point of view. As an art, designing depends mainly upon experience, skill, and judgment, modified by commercial limitations. Design, as an art, cannot from the nature of the case, I think, be properly taught in college. Designing as a science is based on the fundamental laws of electricity. magnetism and mechanics. This phase of designing can be taught to students, and is an important supplement to the study of dynamo-electric machinery.

The Seminary Method of Instruction.

The seminar may be regarded as a form of laboratory work in which the library is the work-room, and the books and periodicals on electrical engineering are the pieces of apparatus. For many years I have used the seminary method with the object primarily of cultivating in the student the habit of reading systematically the current electrical periodicals. Special topics are assigned to the students for investigation, and their reports made in writing are read and discussed before the class. The latest developments in electrical industries are discussed and matters pertaining to thesis work are presented by the students, either in writing or orally before the class.

The special advantages possessed by the seminary method are as follows: It gives familiarity, in the proper way, with the resources of electrical engineering literature; it requires discriminating and substantial work of a kind not demanded by other educational methods; it furnishes valuable information to the student on topics which for lack of time cannot be fully developed in the recitation and lecture; it stimulates the student's interest and is a relief from the monotony of the formal recitation; as an exercise in English, it may be more valuable than the regularly prescribed essay or theme, for being merely a means to an end, self-consciousness is lost, and individuality in style is permitted freer play. The seminary method is most successful when used with advanced classes of limited size.

A natural outgrowth of the employment of the seminary method is the discovery by the student of the need of a system by which information on a given technical subject may be easily found. Here, then, is the opportunity for the teacher to introduce the student to the various published indexes to engineering periodical literature. But printed indexes are only of limited use, as most of them do not pretend to keep up to date. For keeping track of current electrical literature the only satisfactory method I have found is the card index system. When in reading a journal, I find an article which I will probably need again, I make a reference to it on a card with a brief abstract of its contents, and file it away under an appropriate heading in a card cabinet. In connection with the electrical engineering seminary at Lehigh, a part of the work consists in giving the student practice in indexing and making abstracts of the more important articles in the electrical journals. The habit of quickly scanning the columns of technical papers in order to seize the salient points in an article for record upon a card, is worth cultivating in students. For next to knowledge, the best thing is to know where to find it. Accordingly, my senior students are started on making card indexes for themselves, and the habit formed in college is generally continued with increasing advantage in their professional life.

Thesis Work.

In most of our technical colleges the candidate for graduation in electrical engineering is required to devote a part of his senior year to writing a thesis. The function of the thesis, it seems to me, is to bring to a focus on some definite object all the accumulated knowledge and experience of the student. To be most valuable, the thesis should be largely experimental in character. Some definite topic or investigation is first chosen with the approval of the instructor. The student then consults the published work of others along similar lines to find what has and what has not been done. Next the plan of campaign is settled and the instruments are standardized. After the experiments are made, the results are corrected, tabulated, plotted and discussed. Finally, conclusions are drawn from the results.

From the standpoint of training, it matters little whether the work done or the conclusions drawn, are old. The main point is that the work be independently performed by the student and thus far original with him. He should be thrown on his own resources and be expected to accomplish independently definite results. It falls to the lot of very few undergraduates to succeed in making a discovery, or even to make any real contribution to knowledge. Nevertheless, thesis work gives peculiar opportunity for the exercise of the critical faculty, for the following of scientific methods and above all, for the patient overcoming of experimental difficulties. And as a trial of strength and a measure of character thesis work is unsurpassed among the activities of the technical student.

In conclusion, I wish to express in the strongest terms my conviction that safe rules to follow in laying out a course for electrical engineers are: to teach thoroughly those things in college which are fundamental; to devote little time to highly specialized subjects; to introduce the student to those branches of knowledge which in his later life he can acquire only with increasing difficulty, if at all; and to endeavor to cultivate in him the hunger and thirst for more and deeper knowledge, so that he will remain a student through life.

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THE EDUCATION OF THE ELECTRICAL ENGINEER.

BY HAROLD W. BUCK.

Electrical engineering is probably the youngest of all the professions, for it has hardly been recognized as a regular profession for more than fifteen years past. As a result, the men who have reached prominence in it to-day have attained their positions f.om widely differing courses of preliminary training; many of them are men who started life in other lines of work and afterward turned to electrical pursuits on account of the sudden growth and importance of the business. In consequence of this, all methods of preliminary education are represented and their relative values may be estimated.

The argument runs largely between two classes of men, one represented by the so-called " practical man " and the other by the theoretical electrician; the graduate of the machine shop and the graduate of the university. Both of these types have attained success, but the correct answer to the argument will probably be found in a proper combination of the two types. In the past some of the most successful electrical engineers have belonged distinctly to the class of practical men with little theoretical training, but the conditions have changed. In the early days of the profession there was little theory or predetermination of results, and work was carried on largely by guesswork, or by cut and try approximations. At the present time, however, such a state of development has been reached that exactness of result is essential to success, and work based upon exact theory becomes imperative.

In a stationary condition of an art a man with practical experience only, may become very familiar with all the existing types of apparatus and, knowing their various applications, may qualify, to an extent, as an engineer. But the extraordinarily rapid growth of the electrical arts places electrical engineering apart from all the other engineering branches, for new discoveries and theories make radical changes from year to year in the construction and operation of electrical machinery. The engineer whose education is based only upon practical experience cannot keep up with the progress and change resulting from it, and falls behind; whereas, the man with knowledge of the theory and a mind trained by the theoretical studies and scientific reasoning, easily grasps the theory of the change and readjusts his mind to the new without difficulty or delay. Many instances may be cited of men who have been prominent as electrical engineers, who have been dropped out of place in the course of the rapid progress which has been made, on account of a lack of theoretical foundation in their knowledge. Those who have retained their positions throughout the growth of the art have done so by persistent study along theoretical lines.

In its present state electrical engineering is the most scientific of all engineering professions. A man must be to a great extent a physicist, a chemist and a mathematician, as well as be familiar with machinery and its design, in order to be a worker in the broadest field. Many of the problems connected with other branches of engineering can be solved by common sense and by one's sense of proportion as guided by experience and by the eye. But most of the problems in electricity are invisible, so to speak, and can be understood only through their expression in the form of symbols.

Probably no one will dispute to-day that the preliminary education of an electrical engineer demands a special training in those theoretical branches, mathematics, physics, chemistry and mechanics, sufficient to train his mind into accurate methods of thought and reasoning, and to supply him with the actual technical information which he will need in the practice of his profession. But theory alone is not all. The human mind is such that it works with difficulty in pure theory without a series of mental pictures to fix and coördinate the ideas, and the study of theory is likely to make little lasting impression unless the physical meaning of the theory is brought out by constant association with actual apparatus which demonstrates the application of the physical law.

The best course of training for an electrical engineer would seem to be a broad course of education in general subjects at the preparatory school before entering college, with practical work, if possible, along lines of simple mechanics, such as carpentry, in order to train the mind into a sense of proportion and the relations of parts, which is the basis of all engineering.

Next a college course with general subjects the first year; and afterward, for the remaining years of the course, those general and theoretical subjects which have a direct bearing upon the practice of the electrical profession, such as mathematics, mechanics, physics, chemistry, theoretical electricity and magnetism, and thermodynamics. This should be supplemented by actual daily practical work with machinery operating by the principles covered by the theory studied, and demonstrating all the phenomena incident to the theory.

After graduation, an apprentice course should be pursued in some large electrical manufacturing establishment where the commercial relations of the knowledge acquired in college can be clearly set forth. Large machines may be operated which are not available at a college, and experience in the installation of large plants may be obtained, and experience gained in the designing departments where all kinds of commercial apparatus are laid out.

After a few years of this training, specialization may begin along the lines selected for the life work, but preferably not before. A man makes a mistake to consider himself a qualified electrical engineer after he has been graduated from college, for he is not one. His mind has been trained into a condition where he can readily absorb the principles of the electrical profession, but that is all, and the subsequent apprentice training is as important as the college course, in order to acquire the broad viewpoint from which to make the correct start in the direction in which a man is best fitted. It perhaps means a smaller income the year after graduation from college, but it means much more at the end of five years.

But theory and practice are not the only elements necessary for the successful engineer. There are many qualities required in common with other professions; executive ability, business knowledge, presence of mind and ability to handle men, nerve and resourcefulness in handling machinery in times of emergency, are all necessary for the successful engineer. These elements can not be acquired in the study of theory and practice alone, and many men who have stood high in their college courses have ofterward failed in the practice of their profession because of a lack of these qualities.

The study of chemistry becomes more and more important as the profession advances, for the branch of electro-chemistry is rapidly developing, and is likely to become one of the largest fields in the application of electrical science.

And almost above all comes a training in the English language. No man who cannot express himself clearly and concisely in writing or in conversation can hope to attain a prominent position in his profession.

The education of an electrical engineer, however, must never be considered as complete. The art advances so rapidly that constant study is necessary, even to keep up with the progress of the times. But an electrical engineer should be willing to do more than this. He should study to keep ahead of progress and do his share toward the instruction of others.

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A PROPOSED REFORM IN TECHNICAL TRAINING

BY EDWARD B. RAYMOND.

Those who are called upon to select a man for certain duties, although able to form in their own minds an opinion as to the qualifications necessary, frequently experience difficulty in finding such a person as they require. Most men do not appear to realize that intelligent and conscientious work is the basis of advancement, and that industry guided by intellect is invincible. Although this statement may not be generally appreciated, it is the result of many years of experience in the selection of employes, and applies to college graduates as well as others This condition of affairs is largely due to early training. Young men who have been reared without due consideration of the economy and self-denial which has enabled their parents to support them while they were being educated, do not take their life work with the necessary earnestness, and are apt to drift along without thought as to whether or not their efforts are tending in the proper direction.

As under existing social conditions there can be no scientific selection of parents, we are necessarily compelled to deal with the problem as it confronts us, so that it is by no means a simple matter to determine the most suitable future employment for a boy who has not yet developed any leaning toward a distinctive line of work.

When a boy enters the High School, either parents or teacher should decide upon the line of his life work. It is too early for him to judge of his own natural ability, and it is the experience of the writer that most college graduates fail in determining their proper sphere of action, and this is usually apparent to themselves. It is so seldom that positive tendencies appear in a boy, that his natural ability should be carefully studied, and a decision reached as to his future course.

Some of the great masters of the violin will not undertake to teach a pupil who has passed his eighth year, as they hold that the initial training should begin at that age. The writer believes that a similar rule should apply to engineers, and that this work should be started in the High School.

Supposing that electrical engineering has been chosen. What qualifications are essential to success? The student should possess health, character, courage and intellect. He should be thoroughly impressed with the understanding that work, hard work, constant work, is the absolutely essential foundation for future success.

These conditions refer more especially to young men of average ability. The exceptions, who are generally recognized as men of genius, are exotics, and the ordinary rules of advancement do not apply to them. They soar above their colleagues by reason of their superior fitness, and we admire and honor them for their recognized ability, without attempting to analyze the causes, for we know that to be impossible.

Every man has the ability to do certain things with the best possible results. One of these things is work. But in addition to this we should have trained minds, and accumulate knowledge of detail.

There exists in the electrical profession above all others. a demand for the lowest grade of work as well as the highest. The engineer should be thoroughlv trained in the various lines of practical work, in order to instruct or guide others. He must possess the necessary data, and his mind must be trained to utilize it, in order to make the proper calculations, and predetermine results. While all this is true in any branch of engineering, it is especially so in the electrical, as we cannot rely simply upon judgment and intuition. Something more is required to enable an engineer to design and calculate properly the required output of an induction motor, or determine the phases of cross-currents between alternators, whose prime movers are pulsating in frequency, or hundreds of other cases arising in practice.

To sum up, therefore, we need broad-minded men with intellect, strength, training and purpose. How can we best obtain them? We naturally turn to the college—but how much is asked of it?

Men have entered without knowledge of the line of work they are to adopt; often deficiently trained. Their view of life is a fraction with ease and comfort cubed as the numerator, with work to the one-third power in the denominator. To make successful men, this fraction must be reversed. If not done in college, it will be done through stress of the duties which the graduate assumes upon beginning his life work. If this training comes too late, another man already seasoned will forge ahead, for the handicap is too serious for a term of active life, none too long at the best.

Our professors, then, should be men of force of character as well as of intellectual attainment, and the courses at college should be so arranged that recitation rooms and laboratories may be regarded by the students as we look upon our offices.

At this stage of the young man's education, it is the writer's idea that details should be put into second place, as at that time of life they are likely to be only superficial.

The technical college should attract by its atmosphere only men with a purpose, and so the training must be correctly prepared. Some of our colleges make a poor showing in this respect, possibly from improper organization, failure to reach the individual, or inability to inspire the working spirit. It is the writer's opinion that the colleges should return to the district school principle by stopping elective courses, contracting the list of studies and by encouraging the students to specialize. Then, if the professor is able to get hold of each student personally and instill into his mind the necessity for hard work, a long step will have been taken toward the perfect engineering course. The young man graduated from such an institution will go out into the world with a real equipment for successful work in his particular sphere of usefulness.

One of the most essential qualifications of the successful engineer is that he shall be filled with a desire for continual study. Then is the time for him to get his knowledge of real detail, amplifying the general knowledge obtained in college by practical investigation. In short, the college graduate should consider that the knowledge gained at the university is only a start and not a suggestion of a finish.

The writer is a strong advocate of the strictly technical course in the training of electrical engineers. The technical college should drop from its curriculum studies which are likely to be taken up after graduation. The writer believes that such a college will turn out men better qualified for professional work, for when properly trained the graduated engineer will devote a portion of each week to study, and will do this from a natural inclination to study. Details of all subjects that he lacks will be obtained without great effort. As he accumulates money, he will naturally turn to political economy and business law; reading will turn him to history, and daily writing will lead him to use good grammar and expression.

The chances of success in the case of a man thoroughly grounded in technical information are vastly better than those of the man who has gained general information at the expense of technical training. This point is well illustrated by the wonderful success of many of the most noted men in our profession without college training. They had the essential characteristics for success, mind, application and a desire to study, and their success has been the result of those qualifications.

The ideal college, then, would be that which teaches simplicity, concentration, hard work; which discourages all that is superficial; which weeds out the studies that are not essential to the particular course being pursued, and devotes all the more attention to those that are essential.

For the boy in the High School who intends to be an electrical engineer, it may be suggested that for about six weeks of his last two summer vacations at the High School, he should work in the machine shop of some manufacturing electrical concern. This will give him very valuable initial experience. During his college course the student in electrical engineering should spend a part of each summer in similar practical work, supplementing it, perhaps, with work in a foundry or pattern shop. The draughting-room at college would mean much more to such a man than to the ordinary student.

The writer would suggest, therefore, in line with these ideas, that from college electrical courses such studies as French and German, rhetoric and English composition, history, English literature and political economy, be dropped. One college, to the writer's knowledge, has, besides all these studies, dropped bridge construction, surveying and highway building. In place of the studies discarded, more stress could be laid upon mathematics, physics, mechanics, chemistry, thermodynamics and the laws of electricity. There should be enough of these studies to give, in addition to mind training, excellent detail knowledge of the subjects studied.

A feature of the college that may be made especially interesting and instructive is the arrangement of frequent lectures, or talks, by men eminent in their profession. Such men are always willing to give to others the benefit of their own great experience; and their talks must be inspiring to the student, even if the lecture is not understood in detail. Such talks are instructive for the professor as well as the undergraduate, giving excellent inspiration by illustrating what has actually been accomplished.

In conclusion let me say that I do not wish to give the impression that the college is a failure. It is doing wonderful work, and deserves great credit; but in electrical engineering education as well as in everything else, there is nothing that cannot be improved.

Discussion.

Papers by President Charles P. Steinmetz, Dr. Samuel Sheldon, Prof. R. B. Owens, Prof. William Esty, Mr. Harold W. Buck, and Mr. R. B. Raymond, at Great Barrington, Mass., June 21, 1902.

PRESIDENT STEINMETZ:—Gentlemen, the papers announced regarding the education of electrical engineers have been concluded, and discussion is in order. We have here an assembly of the most prominent electrical engineers from various parts of the country; from educational institutions, from manufacturing companies and from the field of consulting engineers, so we may expect a very interesting discussion which I call upon Dr. Perrine to open.

DR. PERRINE:—Our President asked me about three weeks ago to write a paper upon the subject under discussion. As I have been trying to make up my mind on the subject for seven years and trying to write such a paper for seven years, I came to the conclusion I could not do it in three weeks. In looking over all the papers this morning, it seems to me that all, except possibly that of our President, attack the problem from essentially the wrong principle. The authors have taken up the question of what shall benefit the electrical engineer. I think that the electrical engineer's training and technical training in general should not be taken from the view of the technique at all; I go back to the old school man who invented a word, applied to certain studies and called them the "humanities." He builded better than he knew, because while he meant Latin and Greek by "humanities," he expressed the studies that the world is interested in. To-day the studies that the world is interested in, the humanities, are the sciences, and in the concrete form the sciences are engineering. Now, then, I think that our problem is not the training of the technical engineer, but is the education of the man, and that should be our fundamental principle; consequently I think that the college should be a place where the man is grounded, and the technical education should belong only to the post-graduate school. In my own experience I have had a remarkably fortunate training. I was first trained in academical knowledge and in my two post-graduate years I went into the laboratory where we had a man who could teach, and as apparatus we had two tangent galvanometers and one Thomson reflecting galvanometer without a shunt. When I began to teach I found that we had between the physics department and my own $2,500 and three old motors. Such conditions made me necessarily study the importance of the laboratory work, on which much stress has been laid here to-day, and I have come to the conclusion in my work and in the results I have seen from my men, that the laboratory work needed in college, is the work that is devoted to the fundamental principles and not to the technical training in particular. There is far too little physics; there is far too little of fundamental mathematics; there is far too little of chemistry and other essential branches. In all of our technical colleges, physics is taught from one point of view, and a man is taken out of the physics course as rapidly as possible, and put into technical studies where physics is used from another point of view. The study of electricity and magnetism in the physics course begins with pith balls and works up historically, logically, only because it is historical; and the minute you get to engineering problems, you have to begin from the energy standpoint, which is an entirely different standpoint. This illustrates one of the deficiencies of the connection between our technical courses and our science courses. Primarily, a technical student should be a scientific man. In getting out from under the miasmatic influences of the church, we have forgotten very often, true religion, and we have forgotten that one phrase in the Lord's Prayer " Give us this day our daily bread," and I want to emphasize the word " give," We have forgotten that to a man who does his best work, whether he lives or dies for it, his daily bread is given; and we all think that we cannot rely on that Lord to give us our bread, but we have got to earn it; and so the technical student comes in and says, " How can I earn the most money." He is not a scientific man; he does not feel that the first thing for him to know is to know the truth and to be square with himself and square with the facts, and try the hardest to find out the essential facts; he tries in preference—and the college professor is usually to blame for allowing him to so try—he tries to get a bundle of facts in his mind which are similar to the tools in the box of a machinist that will enable him to earn a salary. In one electrical engineering college in this country the teaching is done almost entirely by illustrating before the student the types of apparatus that are made by the various manufacturing concerns in all their details; the professor begs, borrows or steals blue prints, has them reduced to lantern slides, shows them to the student and gives them copies. One told me with pride that the General Electric Company sent out in the wild woods some apparatus. and the drawings did not go with the machinery, and one of his men looked among his college blue prints and saw where all the bolt holes went and put that machine in place. Now, that is the extreme of that sort of thing; and there is entirely too much of it; there is entirely too much of the idea that you must teach a man that with which he can get a position. You should not teach a man how to get a position, but how to hold that position. Now, as regards the laboratory work, I congratulate Professor Owens on having money enough to build that laboratory; but if I had to use the laboratory, I would not know what to do with it. You can teach a man in that laboratory how every different type of machine is designed and how it is tested and everything of that sort; but a man can learn ten times as much who devotes six months of his first year in the laboratory finding out what is the resistance of a wire in every conceivable way. When a man has once measured the resistance of a wire in every way that resistance can be measured, and when he has a piece of wire three feet long, to the resistance of which he can swear, he has learned about one-half of the measurements in electrical engineering, and he needs to study one or two machines, as our President says, so that he can go back to the principles of design and understand what the principles of design are; but to test and work up the idiosyncracies of an old Brush machine or this, that or the other machine, I do not think it is valuable. Neither do I think it is valuable to have the wires run for him; that is valuable in a research laboratory where you do not want to waste a man's time, but to have a college equipped in a way that is far better than any of the laboratories of the engineering establishments where a man would have to work, I think is putting things too readily into the hands of a student. I remember a number of years ago a discussion of this point in connection with some of the work in England. The Engilsh *Electrician* had a sketch of the boy dropping into lunch with his father, and his father saying, " where have you been this morning ?" " Well, I have been out to college and have obtained the mechanical equivalent of heat, and had a cricket game." And I am glad to see that Prof. Owens whom I am criticizing here, has not gone to the extent of laying out boards with punched spaces on, showing where each instrument is to go for each particular test that he is to call for; there are a number of colleges where pre-arrangement is carried to that extreme now. A man given all these helps does not know how to handle work; he does not know the essential principles of handling work; but if a man knows how to measure things, when he comes to measure a dynamo, he can do it just as well as he can measure anything else; and the measuring of a dynamo is no different from measuring any other piece of apparatus. He wants to know how to get self-inductions and what they are and how to get resistance and what resistances are, and so on with all the various measurements. He wants every one of those, and every college should be equipped with a research laboratory where everything is at the hands of the man who is sufficiently far advanced to go into research; but I do not think the freshman student wants to be put in the position of the research student nor be allowed to go within a thousand feet of the research laboratory. Another thing, I want to criticise is the college professor, nearly every one of them. In the first place, I think that a man has an everlasting and unlimited nerve who starts in to teach students who has not been a practical engineer. Again, I think that every man who is teaching students should find out what the world is doing, not by listening to engineering discussions in the societies—do that, by all means; not by getting such blue prints as his friends will give him—do that by all means, too; but not less than once in five years, and preferably once in three years he ought to spend a year in practical work, and I think that every college professor in this land ought to get himself so close to practical work that practical men will be glad to have him in their establishments for a year. I know lots of these fellows before me here to-day that I would be tickled to death to get, even though I could not keep them, and that is the way the college professor could keep up to the times. We cannot expect books to be published fast enough to show how this rapidly changing art is varying, because the men that are doing the work are too busy to write the books; and furthermore, the books are written by men who have been trained in these technical courses where there are no techniques, and do not know a fundamental machine, so, when they discuss a machine they do not discuss its fundamentals, but describe its wheels; consequently, our text-books suffer as well as our educational courses and our students suffer from lack of fundamental principles. I am glad to hear President Steinmetz bring up the question of examinations. It has always been a hobby of mine that examinations have no place or use in a university, as they are ordinarily carried out. I do believe that once a year, the students should know that he is to be examined; and I believe that the professor who enables the student to get a line on the kind of examination he is going to give is playing into their hands and doing less than educating them. I believe first that an examination should be given because no man knows who has not done it, the value to a student of being compelled in three nights to review a whole subject. Then, when you come to the examination, my practice has always been and I believe it is right, to give three or four questions and ask the students kindly not to consult with each other, but to consult with all the books they can find in all the libraries in the country, and bring the answers in in about a week; and that sort of an examination calls for a review and it enables one to know whether a man has learned that subject or not. I had a great deal of trouble at Stanford, with one of the mathematics faculty. I wanted to give a course in differential equations. There was no such course there. I went to the mathematics faculty and finally got one fellow who said he would do it, but he added, " your course is wrong." I went back to the men and told them I had obtained the course. They said they knew that fellow and would not take it from him. Finally I said, " You put me in an embarrassing position; I have got this course for you." They consulted and came to me and said, " If you will guarantee that that man won't grade us and won't mark us at all, we will take the course," and there was never a more valuable course for my students and there was not an examination or anything connected with it; each man studied it because he saw in the work that I was giving them where there was the application. Now, I had rather see a college equipped with no laboratory at all and where mathematics is taught to its limit and where electricity and magnetism are taught to their limit, a college where chemistry is taught and where molecular physics is taught and mathematical physics is taught, than a college equipped with wonderful laboratories where men spend their time in learning things they can learn better in the first mechanical institution they get into. The suggestion was made by Mr. Raymond that men work in machine shops during their vacation is admirable, provided the men can get such a job. I understand that is one advantage that the Lehigh students have; I don't know whether it is true now, but in the old days the Bethlehem Iron Works used to take all the students who would apply in the summer. That is the sort of thing I believe in. Another thing that was inaugurated years ago at Lehigh that I believe in—I don't know whether it exists there now or not—Professor McMullen who is now at Princeton, inaugurated the course of going through shops, studying machines, making drawings from memory and then dimensioning the parts and correcting the drawings. That trains a man's eye, so that when he sees a machine he really sees that machine and knows what it is. That sort of training is ten times more valuable than shop training. He will get shop training better in six months in a practical shop than in four years in a college. These things I feel very strongly, and I feel that the men that are being trained in the colleges are being given too much of that which shows; it is due to the fact, as President Steinmetz says, that there is competition between the colleges; it is just as sharp as any competition that exists in trade, and it is moulding a great many of our courses. The colleges like to bring the parents of a prospective student into a gorgeous laboratory and have them see belts whizzing and all that. It is acting as an injury to the men; they are not coming out with the same course in physics and the same understanding of everything in physics, not simply electricity, but also light, heat and chemistry; it is now a part of the business and so I go back to the essential training as a scientific man; but I do not agree with the idea that literary training is to be left out altogether. Our best scientific thinkers in the world have been men who have been strong in literary work. And there is another thing that we must think of, too, and that is that a man earns his daily bread here in this country to live, and not to earn money; and a man without literary training is only able to live outside of his profession, in the novel of the present day. So I feel that a man needs a strong literary training, a strong scientific training and a strong technical training, so that he is not absolutely ignorant of that side of the work when he goes out into the world.

MR. RAYMOND:—I would like to hear Dr. Perrine state his opinion as to the study of French and German.

DR. PERRINE:—Only as literature. I studied Latin and Greek for four or six years; I never could say I could translate a page of anything except some of the exceedingly easy things, but it did me an immense amount of good, because I got into literature, the grounding of the language. I think our President expressed that perfectly when he spoke of English being taught by the philologists; we don't want philology, we want literature, and it doesn't make any difference whether it is in French or German; whatever a man can learn; if a fellow can learn and appreciate French and German, let him do it, and Latin and Greek; but if he cannot appreciate a foreign language, let him take English; he will get the same training in literature from them all.

PROF. MORGAN BROOKS:—May I call attention to the substantial agreement of Dr. Perrine's remarks with Mr. Esty's paper, although Dr. Perrine said that he disagreed with everybody except the President. With regard to the value of language study, knowledge of at least one foreign language, be it French, German or Chinese, is desirable from showing that other nationalities have quite different points of view from our own; and further, I believe that having obtained the idea of a foreign language, one would, for instance, go to the Philippines and learn Spanish much easier than if he had previously acquired no foreign language at all. The training of the imagination—ability to form mental pictures—developed by such studies as geometry, is also of great value. I should say that the new proposition of Mr. Arnold's regarding electro-pneumatic devices, requires for its production an amount of imagination not given by strictly technical education. Almost any thorough knowledge proves useful in unexpected ways. A general education gives not only ability of expressing one's self clearly, but affords a sense of proportion, the relation of technical affairs to those non-technical. Add to this a knowledge of men, and the engineer is better able to explain, say to the directors of a corporation, the strictly technical points of some proposition upon which his advice has been sought.

MR. STANLEY:—There seems to be a good many expressions of opinion as to the training an engineer should have, and those opinions are very divergent. We are called upon to study the kind of course, the kind of training, that a man who expects to follow the engineering profession should take. I say " expects " advisedly, because he probably goes to college, to the technical school, for the reason that he has seen some friend who has had that line of training engaged in that line of work, whose course he wishes to follow. I disagree most heartily, most thoroughly, with Mr. Raymond's notion of the education for such a man. It seems to me that you thus take away from him nearly all the pleasures of life. In the first place you restrict him to that sort of duty that a soldier follows; he is to be trained to do a certain number of duties, and do those without mistake. If we are to limit the engineering profession to those men who can only do certain mechanical or engineering or electrical duties in a certain way, then we must take from it all the men who are to carry the burdens of the future, to solve the problems that are coming on. There can be no inventors, because there can be no imagination developed by this course of training; and it seems to me that we restrict our engineering work to its very narrowest limits. But there was one significant occurrence this morning that seems to be a final answer to this question: Every paper that was read this morning on this subject was presented by a man who did not have such an education; it would have been utterly impossible for the papers that were read this morning to have been prepared, and to express therein the sentiments and the views which they gave, if the men who presented them had had this limited, mechanically devised system of education; it could not be. I agree with Dr. Perrine in nearly everything that he said, and would point out that the men who are really relied on for the work of the world, are not men who are trained and directed and steered and personally conducted every moment through a college course. These cannot think; not on them must we rely, but on the men who are inspired by the work that is about them, inspired by the work that has been done in the past, and inspired by the hope that they may take some part in the work of the future; on this class of men this country and all the countries of the world and this profession and all other kindred professions must rely to bear the great burdens that are before us.

PROF. W. E. GOLDSBOROUGH:—I have been very much interested, very much impressed by what has happened this morning. I think that if I could have the men that Mr. Raymond has pointed out we should have, if I could have a class—say of thirty men—such as he has said we ought to have, I could develop them into engineers that would make the world fairly buzz; but we do not get that kind of men; we have just the ordinary young men that come to us. These we must train; these we must put in a way to serve their country and their fellow men. You gentlemen can tell us about the ideal way of training a man. Dr. Perrine has told us about the way a man should be trained, and I agree with him heartily. If a man has the time and has the money and has the ability, that is the training he should have; that is the training I want to give him, *but it is often impossible.*

Often a man has to take a training which is crude, which we know is crude, but which is best adapted for him because he has not the money or the time to spend for a better one. He may not even have the mental capacity for a better training. Nevertheless, we put him in a way to earn a good living, to enjoy himself in life, and to be of value in the engineering world; and this is accomplished without the necessity of his going through the work in the very highly thorough way which some of the gentlemen have mentioned, but which is impossible to about 50 per cent. or more than that of the men whom we get. We usually have a few men—five or six in a class—whom we know are thoroughly fine men, capable of developing into bright minded engineers; but the others are not of this class. Mr. Raymond has had part of his trouble from the fact that the men whom he gets are average men or men below the average. If he could get only first quality men, that would be another matter; but we are not all first quality men ourselves. I think we must take cognizance of the fact that the educators of this country have to deal with rather a difficult problem, and therefore we must judge of the college courses, as they are now administered, by the results which they produce. The best engineers that we have in the country at the present day are the product of these colleges. The educators in engineering schools of this country, I believe, are striving to give the young engineer the training he most needs. It would be foolish for them to attempt to educate men in a way that would not meet the requirements of the engineering profession at large. If men were educated just as Dr. Perrine has specified, they would go to the various manufacturing companies, lighting plants, railway plants and no one would have anything to do with them; why? Because they would be so highly theoretical in their view of engineering as a broad problem, that the people would not know how to adapt them to their purposes.

DR. PERRINE:—I never had a student that didn't get a good job.

PROF. GOLDSBOROUGH:—Perhaps the student had a good man to help him get a good job.

It is only fair in view of the fact that the college professor has been made a target this morning, that the college professors should say something for themselves. I won't say very much about college professors; I simply ask you gentlemen to look over the names of the men who have been presidents of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Look through the country and find the men who have done the work in the INSTITUTE, compare the proportion of work that the professors have done which is recognized as being good, with the proportion of work that the profession at large has done, and draw your own conclusions. It is not always necessary to defend the college professor. Now, suppose all of us had gone through a thorough business engineering training and had become the men whom Dr. Perrine says we ought to be, before we took up our educational work. I will guarantee you, gentlemen, if we had done that thing we would have never taken up educational work; we would have become fascinated and absorbed by engineering problems of various kinds, and we could not be dragged into it. You cannot take Mr. Arnold and make a college professor of him; he wouldn't have it.

MR. ARNOLD:—He wanted to be a professor once.

PROF. GOLDSBOROUGH:—Wanted to be; but found there was too much that was attractive in engineering work at large. Now, the college professor takes this calling up and makes himself a man who is capable, who understands the student; he gets some appreciation of what that student can grasp, and then goes to work and moulds him up. I think the majority of engineering professors go out into the field. I know I take the greatest pleasure myself in visiting every conceivable factory or plant of whatever kind it may be, talking with men, trying to find out what they know, trying to get in sympathy with the engineering profession at large, and using the information thus gained as best I may in the talks to my students to inspire them with the fact that to be an engineer is a great thing and that they should go into it with all their hearts and might; but when you are telling these things to a turnip, it does not create any sensation at all. In the President's address, there are one or two points mentioned which I will speak of, as I think they should not be passed over, and I hope I will be understood. I appreciate as being very valuable to us, a great deal that the President has said; anything I do not controvert will be taken, then, as having been accepted by me.

As to the competition between colleges: Now, that has been brought up as a bad thing. Eliminate competition between industrial enterprises in this country, what will you have? You will have stagnation. It takes competition between colleges to throw us into the spirit of the thing, to make us think the thing out, to develop good motives, to put them into execution, and make good engineers. If the colleges should stop; if I do not try to find out what is doing, improve my work, make it fit into our advancing education, I cannot give you the men you need; it will be impossible. We must have legitimate, proper competition between colleges as between everything else; it is absolutely essential to the growth and development of our colleges. The President makes frequent reference to the fact that we should teach young men only the bare fundamentals, and mentions in his paper the bare fundamentals in mathematics as well as in all other departments of knowledge. I agree with you that the obtaining of the fundamental idea is the key to the situation; but suppose we stop for a moment and think of some subject that we have studied; if we have ever gone through very conscientiously a long series of investigations, we now retain but a small part of the whole. If we take a man through that very eloquent book that Mr. Steinmetz has written, when he gets through with it, he will have absorbed only a small portion of it, but he gets something and that he will retain. We have to take the boys beyond the fundamentals in order that they may get the fundamentals; we take them beyond in order that they shall absorb the fundamental things they need to know.

I do not think it is necessary for me to say I believe men should have a pretty general culture before they take up engineering. It is absolutely essential. If they are going to be broad-minded, fair-minded men, whom we want to have here, they must have something more than a sordid engineering education. Mr. Raymond would be driven out of his experimental room if he had nothing but the men he has specified about him; it would drive him crazy; he would not stand it.

Now, as regards another point Mr. Steinmetz has made, about memorizing. I think the great engineer or the great man is a man who can load himself, who for a short time can remember a great deal and can bring it out and use it to the very highest efficiency, and then throw it off and relieve his mind of it. We want to teach our boys how to meet an emergency; we want to make them able at a certain definite time to fill themselves, to enthuse themselves with a subject and come up and meet that emergency, and having met it, be able later to turn themselves to something else. This is not mere memorizing. I do not believe in anything that could be likened to a poll-parrot method of expressing one's self. Boys must understand the underlying theory; they must study the subject thoroughly if they are going to be successful. I think the finest thing in the world is the use of a text-book which has a great many typographical errors in it. Why? For this reason: That when the student has used the book and has worked with it and struggled over the mistakes and finally righted them, he has gained this one great idea, that just because a thing is in print, just because a man of authority tells him it is right, he should not believe it; he should go right to the bottom of the thing and find out for himself. Any instructor who appreciates the work he has to do, appreciates the fact that he must not have the student simply feel that because a formula is in a book, he should use it; there is liable to be a mistake in it, and he should go to the very root of the thing. If a boy goes to a college and never has to take an examination, when he goes out into life he does not know how to meet an emergency. We must throw boys into positions which develop the ability to stand firm in times of stress and not flinch; we must develop this trait in them, or they won't be men —and the sooner we can develop it the better.

I am very strongly a believer in the value of design in the training of electrical engineers. I may be wrong; a number of gentlemen whose opinions I must respect, have said that they do not believe in teaching design; but I am of the opinion that if you let a man operate a steam engine all his life, and do not teach him steam engine design, he never gets the true feeling that he is in touch with the engine. In order to understand what the distribution of the flux in the air gap means, and the effect it has on design, a student has to get right down and figure the thing out, and see the effect of saturation; he has to get so that he appreciates it; he must almost feel that he is inside of the air gap; and then he begins to understand it. I do not mean that the boys ought to study designing because they are all going to be designers; that is not the point at all; but if they know designing thoroughly, they will understand their machinery better; they will be able to overcome difficulties in operating plants better. It is no longer an impossible thing for a dynamo to be designed in a college which will operate successfully after it is built. I presume ten or fifteen years ago that may have been true; it cannot be true any longer. We have far more information at our command than the engineers in the factories think we have. I go to one prominent works and the engineers tell me how lamentably the engineers of another establishment have failed; I go to the other place and they tell me the reverse proposition. If the manufacturer does not feel that any other manufacturer in this country can build a good dynamo, I do not feel bad if they think I can't build a good dynamo.

I think that Dr. Sheldon's paper is very excellent indeed and I enjoyed Prof. Esty's paper; I enjoyed Mr. Buck's paper; but I cannot agree with Mr. Raymond in the position he has taken with reference to the instruction which should be given our young men. It would not do at all.

PROF. C. A. ADAMS, JR.:—I cannot tell how much I have enjoyed these papers on the Education of the Electrical Engineer, and the subsequent discussion. We who are teachers cannot help profiting by the good advice given on this subject by practising engineers, by those who purchase our product, so to speak. But while welcoming that advice most heartily, I cannot accept it at all points.

Mr. Raymond has advised us to omit all general or broadening studies from our curriculum; to confine the student to the strictly technical, and says that the time for literature and the like is after a man has become thoroughly established in his profession. If this were true it would be immensely convenient, since one of our greatest problems is to get enough of the technical into a four years' course without slighting the more general training. But my feeling about these general studies is much like that of the Catholic priest about his religion when he said, "Give me a boy before he is twelve years old and you may have him thereafter." The love of literature or the habit of easy and accurate expression of one's ideas, are not easily grafted on, after maturity, but should be bred in the bone and the earlier this training begins the better. As to the need of such training we have to-day had ample evidence from some of our ablest practising engineers who advise relegating most of the strictly technical to a graduate professional course, and in this I agree most heartily, although there will probably always be a demand for a four years' undergraduate course.

Engineering is just as much a profession as law or medicine. Who, more than the engineer, needs a broad training, needs to be able to express himself clearly, so that the public or the capitalist will have confidence in him and his plans? Why is it that the control of so many of our largest engineering undertakings, public and otherwise, are under the control of lawyers and business men? We first of all want a man, and then an engineer.

Of course, there are all kinds of engineers and there will continue to be all kinds of training offered for engineers, and some men will be good engineers no matter what their external training; but I have been speaking of the ideal engineer, of which we see a few among us. We want now to offer every opportunity for the increase of that number; possibly many members of the INSTITUTE do not know how much the graduate idea has already taken hold in engineering education. For several years nearly 50 per cent. of the students in my fourth year courses were college graduates and some held high degrees. Moreover, these men were almost invariably the best men in the class, not only because of their maturity, but because they had chosen this field of work advisedly and not by accident, as is the case so often. This unwise, unconsidered choice is one of the greatest burdens which the undergraduate technical school has to carry.

President Steinmetz has emphasized the importance of training in the fundamental principles rather than the memorizing of a few of the applications of these principles. With this I am in most hearty sympathy. I am a strong believer in a thoroughly scientific training for the engineer. In fact, I emphasize "fundamental principles " so much in my classes that that phrase has almost become a nickname. But the principles can only be grasped through their application, the abstract through the concrete, and the more practical the application the more useful it is in fixing the principle in the average mind. I even go so far as to include under this head the design of electrical machinery as one of the most effective methods of fixing the principles of electricity and magnetism, bringing in as it does a most thorough problem in the magnetic circuit. It is not intended to turn out fully equipped designing engineers, but rather to teach the student the " reason why " in dynamo design, and to cultivate in him the habit of looking for the reason, of applying his principles.

There is one point in connection with laboratory instruction upon which I feel strongly. Every instructor with large classes to handle in the laboratory, finds it necessary to systematize the work, and the tendency is to sacrifice quality to quantity to put the student through a rigid machine with almost no encouragement to think for himself. The idea of completing a certain set task at a certain time predominates over the desire to understand the experiment for the sake of the understanding. I know it is very difficult to avoid this tendency, but it should be avoided at all hazards; it is the greatest weakness of some of our strongest schools.

DR. C. P. MATTHEWS:—I want to add just one word. The professors have come in for a pretty good share of criticism this morning, but I really think that oftentimes the trouble begins in the home. Many boys go to college and take an electrical engineering course, who are absolutely unfitted mentally for that work. Probably the father has said to the mother, " I am sure that John is fitted for an electrical engineer; why, he got my old medical battery out of the garret the other day, and if you believe, he shocked his grandmother." Now, I submit that it is not obvious from this that John is fitted for an electrical engineer; he may be cut out for a specialist in nervous diseases. That is the only thought I want to bring out; that parents must study the boys.

I think boys should not, as suggested in one of these papers, begin to specialize at the beginning of the high school course; it is better to wait until the end of the high school course. Let the high school course be purely cultural. Do not encourage a boy, it seems to me, to follow any particular line at that early age; you may not at that time have been able to decide, from such an incident as that I have cited, as to whether he ought to be a doctor or an electrician, but at the close of the high school course, he will be 17 or 18 years old, and will show tendencies in one direction or another, and a wise parent, having noticed those tendencies, will send the boy where he can develop them. An unwise parent, on the other hand, will pay no attention to the matter. This latter must be so, because we have many boys in the colleges who have evidently been sent there to get rid of them.

PROF. SEVER:—The methods which some men take to enter college are, as just outlined by Dr. Matthews, very interesting. One of my men goes to Schenectady to work for Mr. Raymond. He entered Columbia University in this manner. A friend of his, a graduate in the same class with him from the College of the City of New York, went to his house the night before the entrance examinations at Columbia, and he said to him, " I am going up to Columbia to-morrow to take the entrance examination; I think I will be an electrical engineer; don't you want to go along and be an electrical engineer?" He went; he took the examinations, passed them successfully, and this year he got the degree of electrical engineer, and I expect to see him become one of the prominent engineers of the future, under Mr. Raymond's instruction.

The matter of broad instruction has been considered very deeply by the trustees of Columbia University, and they have placed themselves on record in the following manner—I quote from a report of a committee appointed by the trustees of Columbia, who investigated this subject very carefully: It states that the trustees of Columbia University have announced it to be expedient and desirable that all the professional schools should be placed on a graduate basis, and this policy, having been adopted as to the law school, is to go into effect in 1903. They place themselves on that broad ground to give a wide and liberal education, and it is being very deeply considered by all the different professional school of Columbia University as to the best method of securing this six or seven years' course for the broader education of the student. It is a thing that cannot come rapidly, because it strikes, as you might say, the vested interests; it must come slowly; but undoubtedly it will come. In our circular of general information, attention is called to this broader and more liberal method of education, in this manner: " The combined six years' course is strongly urged and recommended, for the reason that engineers, chemists, architects and professional men need the liberal training offered by a collegiate course quite as much as do lawyers, physicians or clergymen. Experience has shown that those who have taken a liberal course of study and have enjoyed the advantages of such an education before beginning their technical studies, have taken a much higher standing in their profession, have exercised greater influence in the community and have been much more useful men than those who have relied upon a purely scientific or professional course of study."

Statistics are given as to the men who have taken this longer course during the time that the opportunity has been presented by our University, and as a conclusion, this is stated: " Further, there seems to be but little demand for a professional training of this kind, based upon a liberal education." Apparently, the demand must be created. The only way to do that is to slowly abandon the four years' course of concentrated attention to technical information, and put it upon a six years' course of study. I state this, as I desire to define the attitude of Columbia University in the matter of broad and liberal-minded education.

The matter of examinations is one that touches our innermost soul, especially when we have a hundred men in a class, who do not know very much about the subject and whose examination papers we have to delve over night and day for twenty-four hours a day. We believe in examinations. An engineer, when he has to make a report on a proposition, has to work night and day to do that if he is given a limited time. Note Mr. Arnold's method of work, while he was under examination by the New York Central Railroad, and to the surprise of Mr. Pearson got his report in in less than four months. We do the same with our men; we bring them up to a fighting point, make them tell what they know. I urge the men to cram for examinations; I tell them that is what an engineer has to do and I believe in it. A little different method I think I can cite, if President Steinmetz will pardon me. Columbia University had the honor of having Mr. Steinmetz deliver a course of lectures during this last term to our senior students, in electrical engineering on alternating current machinery. As an examination in that course he sent to each man the data and a set of curves for the calculation of an induction motor. Each man was supposed to work out the results independently, at home, in the drawing-room, or anywhere else. I believe they all did it—at least they all have their degrees—but how they did it I don't know; judging from my own experience in laboratory reports, they may have had instruction from other quarters than that which they secured in the class room—my apologies to Mr. Steinmetz if I am wrong. I do not believe in that method entirely.

I am thoroughly in sympathy with Prof. Goldsborough as to the use of designs in bringing out the application of the principles which it has been our endeavor for three years to instill into the men. We do not expect those machines to be built. I had one machine designed that had 110 per cent. efficiency, but the design indicates to the man what the thing is, where the magnetic flux is or is likely to be, where the wire is to be placed; he places it himself; he does it himself, although he does not build the machine. We have been through the Stanley works, we went through them yesterday; I doubt very much whether there are 5 per cent. of the members who visited those works who could tell 10 per cent. of what they saw; and it is our purpose in the engineering schools to show the men where the things are placed and how they are placed, and we use the method of design to teach them that.

As to laboratory equipment, Prof. Owens is an old Columbia man, graduating under Prof. Crocker, and he has had unlimited money with which to install a laboratory. That is quite in contrast with the laboratory in which he pursued his instructions. Mr. Buck also suffered under the same conditions that Prof. Owens did, so far as lack of laboratory equipment was concerned at Columbia University.

We had one Fort Wayne alternator which was belted to the same engine that a Bradley dynamo and a Thomson-Houston arc light machine were belted, and when we added load to the apparatus, we unfortunately changed the frequency of the alternator, and all such things as that; a most imperfect equipment, but you see the result. The arrangement of laboratory apparatus is one that has an unlimited field; we have the perfect arrangement of Prof. Owens and we have the many imperfect arrangements of other universities. I follow absolutely Mr. Raymond's testing department. There is the machine; there is the current; the instruments are in the case; go and get them and connect them up and do the work which is appointed for that afternoon or for that day; get the results. It takes longer, but we do not try to cover as much ground, and what the men do get, we feel they get very well. As to theses, we make a particular point on that, having at least two men work together on a thesis, taking up some engineering subject or taking up some research work. For instance, this year we investigated the inductances of the armatures of the Manhattan generators. Such things as that we feel show the result of our labors on our men during the four years that we have them.

In closing, I can only commend Prof. Goldsborough's attitude regarding his men, his desire to turn out men who are able to tackle every problem. I think that should be the aim of the university; we do not want to take men who are particularly fitted for one factory or another, for one telephone company or another, but we want to turn out a man who has the fundamental principles and who can apply them, no matter where he goes.

PRESIDENT STEINMETZ:—We would be pleased to hear from Mr. Pearson.

MR. F. S. PEARSON:—I have been greatly interested in the discussion this morning. Years ago I was an instructor in technical subjects, and I look back with great pleasure to my experience as a teacher, and even wish that I was back in the class-room. I am thoroughly in accord with the President's paper, as well as with the views expressed by Dr. Perrine, but there are some points which I would like to comment upon from the point of view of the construction engineer. This morning we have had the views of the manufacturer and college professor. I believe in thorough culture for the engineer; still, I appreciate that the technical schools must take the men as they come, and for the time being must make the best of the conditions. I believe one great function of the technical school should be to raise the standard of education; to do away with the student's idea that the chief end of life is to get a good position and salary at the earliest possible time. Years ago it was cutomary for a lawyer or a doctor to study a year or two only before obtaining his degree, and then commence at once the practice of his profession. The leading colleges have discouraged this plan, until to,day there is hardly a case of a practising physician or a lawyer of any standing, who did not complete a four years' academic course before entering upon his professional studies. I think that is the point at which the technical schools for the engineer should aim. They should impress upon the young man who is about entering on an engineering course that the first thing necessary is to obtain a broad general education. If he does this, his salary and all the advantages derived from a technical education will follow naturally as a matter of course. The idea of commercialism which is so prevalent in the engineering schools, I think is all wrong and unnecessary, because while there are no doubt a great many boys who think they cannot afford a seven years' course or even a six years' course, still the poor boy who wishes to study for the ministry, medicine or law, for either of which he requires six or seven years, finds the means of doing so. I learned the other day that one of our largest technical schools is so overrun with applications for admittance that it seemed necessary to find some means of discouraging or keeping men away. They have adopted the plan which seems to me entirely wrong in principle, of materially raising the price of tuition, in order to discourage men from coming. The right principle for the technical schools to adopt is to raise the standard of admission and thus secure a higher class of students; and then when a man is admitted, raise the standard of work in the school and gradually weed out the poorer students, leaving for graduation a class of very able men. I think in a very few years all men who aspire to become electrical engineers will see the necessity of the seven-year course. I believe the engineers should have a thorough knowledge of Latin and a fair knowledge of Greek; not that he will ever need them in his engineering work, but for the mental training and culture that a man gets from the study of these languages, and the great aid they are to him in the study of modern languages. The time required for these studies in my opinion is well spent. I do not agree with some of the speakers here on the question of French and German; I believe that

French and German are essential requirements of every engineer's education. Some of the ablest men to-day in mathematics, chemistry and physics, are writing in French and German. The French and Germans themselves, the Russians and Hungarians, in fact all of the European scientists are publishing their works in French or German, and the American engineer, to be thoroughly posted in the progress of his profession, must be able to read foreign languages. Furthermore, if a man takes up consulting engineering and construction work as a profession, he will very likely be called to foreign countries in a professional capacity. In my experience I have been employed in professional work in Germany, France and in Portuguese and Spanish-speaking countries. I do not pretend to be master of all these languages, but a knowledge of French and German makes it much easier to acquire a slight knowledge of Portuguese, Spanish or Italian, or in fact, any other language, especially if one has studied Latin and Greek; and a man who has a knowledge of French and German so as to speak it slightly and read it easily, is much better equipped for consulting engineering than the one who has no knowledge of them. For this reason I should advocate the study of French and German in the colleges to a sufficient extent to enable one to read them without difficulty, that is, be able to pick up any scientific book or periodical in French or German and read readily without a dictionary.

As regards the teaching of machine design in college, I am a believer in it to a certain extent. I do not think a student can be taught to design a piece of electrical apparatus that will be a commercial success. He must learn that by association with men who have had experience, and long experience, in designing; but there are very few men who have the faculty of applying to practical purposes theoretical knowledge; and even if a man has been taught the higher mathematics and its application to electricity, unless some chance is given him to apply this knowledge in the designing of apparatus in the class-room under the direction of the professor, who can point out to him wherein he is deficient and to whom he can go when he does not understand thoroughly the application of the theory, he will leave college without thoroughly understanding the subject, and it is very difficult for him to acquire this knowledge after he has entered practical work. For that reason I think designing is a very valuable adjunct in a scientific course.

There is one point that has not been touched upon at all this morning, except as the President has referred to it, and I do not quite agree with him in this matter. I think the electrical engineer should have a very thorough grounding in civil and mechanical engineering, as well as in mathematics, physics and chemistry. Electrical engineering is to my mind, without any disparagement of the other branches of engineering, at the apex of the science. The electrical engineer has to do with the development and utilization of energy, and to accomplish this, a knowledge of civil and mechanical engineering must be applied in the construction of the work, and later in its operation. An electrical engineer to be successful should have a thorough knowledge of civil and mechanical engineering, and I feel that the ideal electrical engineering course should extend over seven years; the first two years to be devoted entirely to academic subjects, such as mathematics, Latin, French, German, history, political economy, logic, English literature and the various other subjects a man ordinarily takes in an academic course. The second two years should be devoted to general engineering subjects and mathematics, chemistry and physics, but not necessarily to electrical engineering subjects, among which should be included civil and mechanical engineering branches, such as applied mechanics, graphical statics, designing of framed structures, strength of materials, construction of masonry and foundations, character and value of various materials used in construction, hydraulics, gauging streams, construction of dams and canals, and methods of utilizing water in the development of water powers, steam engineering, thermodynamics, etc. An electrical engineer should understand all of these subjects before commencing his special work to which the last three years should be devoted.

With such a course as outlined, the graduate will be in a position to understand any character of work that may be offered and his promotion should be rapid. In this way we shall have a broadly educated engineer, and one that will be an honor to his profession as well as a good member of society.

PRESIDENT STEINMETZ:—Before proceeding further with the discussion, I should like to give the floor to the Committee on Resolutions, Messrs. J. W. Lieb, Jr., C. O. Mailloux and F. A. Pattison, for the presentation of their report.

Secretary Pope read the report of the Committee as follows:

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, desiring to acknowledge the many courtesies extended to it on the occasion of the 19th Annual Convention of this INSTITUTE, held at Great Barrington, Mass., June 17th to 21st, and to record its gratitude for the splendid hospitality enjoyed by its members and guests, begs to transmit to you this official expression of its sincere thanks.

At the closing of the Convention, held June 21st, the following resolutions were unanimously adopted:

Resolved, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, being deeply sensible of the many favors and courtesies received by its members and guests during this Convention, hereby tenders its sincere thanks to:

Mr. and Mrs. William Stanley.

The members of the Local Executive Committee.

The committee and members of the Thursday Morning Club.

Mr. E. F. Searles of Barrington House.

The Wyantenuck Golf Club.

The Stanley Instrument Company of Great Barrington, Mass.
Dr. and Mrs. F. A. C. Perrine.
The Mayor and Board of Aldermen and Local Committee of the City of Pittsfield, Mass.
The Country Club of Pittsfield.
The Pittsfield Street Railway Company.
The Stanley Electric Manufacturing Company.
The American Telephone and Telegraph Company.
The New England Telephone and Telegraph Company.
The management of " The Aspinwall," Lenox, Mass.

Resolved, that the thanks of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS be transmitted officially to each one of its hosts above named.

Signed	THE PRESIDENT AND
and	OFFICERS OF THE AMERICAN INSTITUTE
Sealed.	OF ELECTRICAL ENGINEERS.

MR. RICE:—Mr. President, as chairman of the Committee on Papers and Meetings, I beg to move the adoption of the resolutions that have been offered, and in making this motion I want to, if it were possible, express to our hosts the appreciation that we feel. I am hardly able to do it; it is more than one can express in a few words. We have been delightfully entertained in your homes.

MR. MAILLOUX:—I am very glad indeed to have the motion made by Mr. Rice, as Chairman of the Committee on Papers and Meetings. I am also glad as a member of that committee to join hands with him and help sustain the motion by seconding it.

MR. LIEB:—A communication from the Albany Institute of Arts in reference to the Joseph Henry memorial, requesting that the matter be brought before the INSTITUTE at this Convention, was referred to the Committee on Resolutions. The communication was accompanied by an announcement, which the Committee lays before the meeting with the recommendation that the matter be referred to the Board of Directors for further action.

PRESIDENT STEINMETZ:—This communication has been laid before the INSTITUTE for proper action, and it seems to be proper to refer it to the Board of Directors, and I therefore do so.

After having had the great pleasure of passing the resolutions reported by the committee, I am only sorry that we cannot attempt adequately to present our feelings of gratitude to the generous people of Great Barrington and Pittsfield.

PRESIDENT STEINMETZ:—It is my very great privilege as President, and I take extreme pleasure in being able here for the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, to present to the President and Executive Committee of the Thursday Morning Club, a very small token of our appreciation of the splendid work they have done and the great results they have achieved in entertaining the INSTITUTE so royally and thereby making a mark in the history of the INSTITUTE by securing results which have never been achieved before, and I am afraid will not be achieved again for a long time to come. I take great pleasure in presenting you this loving cup.

MRS. LANE:—Mr. President and Members of the INSTITUTE: On behalf of the Thursday Morning Club I thank you. This week has been much more to us than perhaps you realize. It has proven to us the strength of our organization, and shown to us that that very strength comes from union. We will keep this beautiful reminder of your visit as a symbol of that union. Again I thank you. (Applause.)

[Adopted by a rising vote.]

The discussion upon the educational papers was then resumed as follows:

MR. MAILLOUX:—My views on the subject of education in general and of engineering education in particular, are somewhat radical, and I therefore expect to astonish and shock some of the members present. I concur heartily with the remarks of Dr. Perrine, who is especially well qualified to speak on this subject by reason of the opportunities which he has had to study it, as a teacher of engineering, as a practising engineer, and also as an employer of engineers in relatively large numbers. I also wish to commend especially the papers of Prof. Esty, of Mr. Buck and of President Steinmetz, which seem to me to contain excellent ideas and to outline the entire subject very intelligently. The papers and the discussion have shown that there are many points on which we all agree, and that our differences sometimes exist more in the definition than in the substance of our ideas.

Victor Hugo, in the first page of one of his great novels (" The Man Who Laughs ") speaks of a certain physician who " sometimes cured, *because of* or *in spite of* his art." I believe that this cynical comment on the art of healing would be a good text for a discourse on the " art " of engineering education, for it is with engineers as with doctors; they " engineer " *because of* or *in spite of* their engineering education. We all know of engineers who have succeeded *because of* their training, as we also know of those who have succeeded *in spite of* it. The text furnishes convenient names for two distinct classes of engineers, from the educational viewpoint: the " because-of " class and the " in-spite-of " class. The constituency of each class will depend upon the definition of the terms " engineering education " or " technical education." The strict academic definitions would reserve the "because-of" class for technical graduates only, or at least for those only who have had adequate special technical training in scientific schools. The objection to these strict definitions is that they would relegate to the " in-spite-of " class too many worthy names, including stars of the first magnitude, such as Faraday, Edison, etc.; and, consequently, the definitions must be extended so as to make education independent of *place*, or *time*, or *method*, of teaching, and so as to accept or admit knowledge as knowledge, just as gold is accepted—for its intrinsic worth—irrespective of *how*, *when* or *where* it has been acquired. I believe it to be somewhat unfortunate for the best interests of engineering education that so many, both among pupils and teachers, " judge the goods by the label on the wrapper." The teacher too often fails to realize and to appreciate, or, at any rate, he too often fails to impress upon the pupil, the important distinction between what one has *studied* and what one has *learned*, or what one *knows*. I will illustrate this point by an incident. Some time ago I had a discussion with one of the technical assistants in my office over certain technical questions which were involved in an engineering problem under consideration. The assistant, who evidently considered his knowledge of a " brand " superior to mine, informed me, after his arguments had been completely refuted, that he " ought to know," because he had studied fourteen semesters in German scientific schools." I informed him that " doubtless he *ought*," if he had studied even a shorter time, but that "assuredly he *did not* " know; that what was really interesting and relevant in this case was, not how long he had *studied*, but how much he had *learned*; not what he had *forgotten*, but what he *still knew*. I then insisted upon having the question in controversy referred to a competent third party, as referee, satisfactory to both of us; and his decision, rendered without knowing either party, was a triumph for the cause of knowledge " which is " and a defeat for knowledge " which has been." This is not by any means an isolated case. I could mention numerous other similar incidents to show that " there are others," and they do not, by any means, all come from German schools—who count as part of what they know, much that they have never known, simply because they once studied it, or studied " at " it.

Prof. Esty speaks of the " common complaint among practical electrical engineers that college graduates are not practical." Mr. Buck argues that the training of the engineer should combine both theory and practice. My own view is that engineers are not practical enough simply because they are not theoretical enough. I believe that if the college graduate knew more of the fundamental theory, he would understand the fundamentals of practice better, and would make more rapid and satisfactory progress than he usually does, in acquiring familiarity with practice. Hence, in that respect, although the college professor might expect me to differ from him, I really agree with him. I strongly believe in theoretical knowledge, but I think it ought to be *thorough* rather than *extensive*, if it cannot be both. I believe strongly that it would be better to teach only the groundwork, the elementals, so to speak, of both theory and practice, and to do it thoroughly, than to attempt to rear a showy superstructure upon a flimsy foundation.

I do not take kindly to the recommendation of Mr. Raymond that the vocation of a boy should be selected and fixed for him by his parents or teachers, while he is still in the high school; and I differ radically with his view in regard to encouraging students to specialize early. I have had a little personal experience with that plan, and I must say I do not like it. I am, myself, an unfortunate example of the boys whose career was selected for them while still in the high school. My parents then elected to fit me for the profession of medicine, and I was schooled largely with that object in view; so I began to " specialize " early. I spent, in the study of medicine, three or four valuable years, and I have often wished, since, that I had devoted the same time to general scientific studies, instead of specific scientific studies. The time was not all lost, for the reason so well stated and illustrated by Prof. Brooks, that *all* knowledge is useful; and the knowledge then acquired by me has been of utility more than once, even in my present vocation. These studies, considered as factors of mental training and development, were of undoubted benefit and value, though not as much so as certain other less specialized studies would have been.

Mr. Raymond's analogy between the violin student and the engineering student, which is presented as an argument in favor of early specializing, is both physiologically and psychologically wrong. The violinist needs *manual* dexterity, involving the power of control and coordination of certain muscles of the arm and hand—the training of portions of the human organism which can attain their full development at a very early age. The engineer needs *intellectual* dexterity, involving the proper education and coordination of his perceptive and reasoning faculties—the training of the brain, the portion of the human organism which is the very last to attain its full development.

Mr. Stanley's allusion to the importance of broadening one's horizon, and his reference to the " pyramid of knowledge," are happy thoughts, full of meaning, which, I think, should be well borne in mind. The further definition of that " pyramid " might be made by reference to Prof. Agassiz's definition of a learned man as "one who knows everything about some thing and something about everything."

The apex of the pyramid represents the " everything about some thing"—or the particular specialized knowledge of the individual in his " specialty " ; and the base represents the foundation of general education, mental training and intellectual development or culture, which are necessary to encompass, support and hold together the mass of the pyramid, containing and constituting the "some thing about everything." The higher the point at which the apex of the pyramid is to be placed, the broader and the more substantial must be the base, and, what is very important, the greater the time which must be allowed in building it. In a word, the process of building a large, solid, finished " pyramid of knowledge," in the human brain, is incompatible with early specializing or insufficient preliminary training and general education. I believe strongly in general education. I believe that education of any kind is a broadening and lifting force which develops the individual and helps him to rise to a higher plane in engineering, as in all other professions. I heartily approve the new plan of Columbia University to lengthen the course to six years, with the first three or four years devoted to general education. It would be better still if the entire six years could be devoted to general training. I have such respect and appreciation for general education, that, were I able to begin all over, I feel that I would devote twelve years instead of six to the preparation for a technical curriculum.

After an experience of nearly twenty years in teaching myself and also in teaching others occasionally, I have come to the conclusion that so far as the *ultimate* result is concerned, it does not make so much difference by what particular course of study the preliminary training of the pupil is accomplished, provided it be broad and thorough.

The objects sought are, briefly stated, to foster taste and develop capacity for study, to make the perceptive faculties more active and keen, to develop the powers of observation, thought, analysis and synthesis, to enlarge the scope of the reasoning faculties, and, in general, to broaden the intellectual horizon. Any process, method or means of training which attains these objects must be accounted good, for it equips the mind with the three graces—aptitude, application and judgment—which are the handmaids of success, that point out and prepare the easiest paths to distinction, making the process of acquiring skill and experience less tedious in *any* vocation. Such a man is placed at a disadvantage only temporarily by the want of " practical " or specific technical training. When he does catch up with his colleagues who have less general but more specific training than he, they are likely to be left behind. It is a matter of universal observation that the individual who has the most broadly and highly trained mind acquires practical experience and skill the most rapidly. The usual comment is that he is " brighter " and " smarter " than the rest. What is really meant is, that he naturally has, or else has acquired by training, more aptitude, more application and better judgment (and the other qualities which accompany them) than the rest.

In regard to practical experience, it is admitted by all that the school is not, to say the least, the best place to acquire it. The most that the school can hope to do is to prepare the student so that he can acquire experience easily and quickly; and, as I have already indicated, I believe that general scientific training is as good preparation as any for this purpose. I concur, to a great extent, with the opinion of Dr. Perrine that students should not be taught too much practical work. While I do not wish to be understood as disparaging practical training in schools, yet I strongly believe that, seeing the impossibility of giving a thoroughly practical training in schools, it is better to waste no time on practical training that could be advantageously and profitably used in perfecting, in broadening and deepening the theoretical training.

One of the great qualities needed in any engineer is *receptivity.* If the young man were drilled thoroughly in fundamental principles instead of being given a smattering of them, together with a smattering of practice, he would not be deluded, as he so often is, with the idea that he has already learned all that is worth knowing, both theoretically and practically, and that knowledge and experience have no new fields for him to conquer. One of the hardest things to eradicate from the mind of the young engineer is oftentimes that very feeling, which, in many cases, amounts to a conviction, to the effect that his technical curriculum and his professors have already given him a panoramic survey of all that is worth seeing, noting and knowing, in the domain of theoretical and practical knowledge. To do justice to the young engineer, let us admit that this feeling represents a phase of human nature which is not characteristic of his age or of his school, since it exists quite generally. It is that same phase of human nature which animates many tourists, who come and go so quickly that they stop only long enough to carry off the dangerous delusion of having seen and learned all, when, as a matter of fact, they have scarcely seen or learned anything. I am, therefore, inclined to think that a smattering of practice is worse than none, and that perhaps a thorough science training would be as good for immediate results, if not better, and that it would be certainly superior for ultimate results. Examples are not wanting of men who have become eminent, both in theoretical and practical lines, whose preliminary training was greatly, if not wholly theoretical. The success that has been achieved by those who have had neither theoretical nor practical training, in technical lines, but who have had merely general intellectual training and discipline, is an indication of the great importance and benefits of a training in which the individual is taught *to think* and *to study*, that is to say, whose mind has been developed to the highest possible degree of *receptivity* and *assimilative* power. I could point to many examples of successful engineers, whose preliminary education and training have been on general lines, perhaps only classical or literary. These men generally understand and recognize, or, at least, they admit their limitations more readily than is apt to be the case among those who have received a strictly technical training. My observations have shown that a little knowledge, especially in practical matters, is very dangerous, because it too often inspires a dangerous confidence in its possessor. Without this knowledge, the student might have had the courage to say, " I don't know." With it, he tries to think, and to make others think, that he " knows," too often to the detriment of his own reputation and of the interests with which he is identified. Dr. Sheldon has surmised quite correctly;—"That which the technical graduate lacks," *is too often* " the broad-mindedness associated with graduates from classical and art courses, and which, as a whole, is considered as an indication of a liberal education."

I now come to an important question which forms a subject of contention, so to speak, in this discussion, namely, the utility of languages. I fully endorse Mr. Buck's opinion about the necessity of a good training in the English language, and about the drawbacks of an undeveloped and uncultivated faculty of oral or written expression. I therefore disagree and most emphatically, with Mr. Raymond, who would drop the study of English, rhetoric, composition, etc., from the curriculum for the training of engineers. The faculties of thought and of expression are so closely related, physiologically, that the dwarfing of one necessarily dwarfs the other. It is my opinion, and I believe observation confirms it, that the individual who neglects to learn the important art of clear expression has handicapped his intellectual faculties to a great extent, for he has not attained his full possibilities in the direction of clearness of thought. I also differ radically with Mr. Raymond on the question of foreign languages. I will first refer to the so-called dead or classical languages. I was extremely pleased to hear so distinguished an engineer as Mr. Pearson put in one good word for Latin. It happens that Latin is one of my hobbies. I began the study of languages at an early age. When I left high school, I had a fluent knowledge of three modern languages, besides a fair knowledge of Latin and a little knowledge of Greek. To-day, the only magazine which I read regularly is a Latin magazine, *Præco Latinus*, which I recommend to all lovers of scholarly Latinity; and I am proud to say that not only have I retained the knowledge of Latin and Greek which I had when I left school, but I have increased my " stock " of Latin, until I am considered to-day, by my good and indulgent friends, as knowing something about Latinity. I have found Latin useful not only as an intellectual rest and recreation, but as a means of mental training and discipline, as a means of improving diction, and as a means of philological, literary, philosophical and historical instruction. I regard both Latin and Greek as a most valuable mental training and accomplishment. I have the same high opinion of modern languages. I remember reading, shortly after I left school, an allusion to the statement said to have been once made by a noted linguist, Charles V., of Spain, to the effect that " a man is as many times a man as he understands languages." I was wise enough to know that a man cannot multiply himself indefinitely, but having then a knowledge of three modern languages, I could realize by practical results, that there was something in this thought, for even the knowledge of only three languages had extended my intellectual horizon; it had increased my intellectual perspective; it had enabled me to look stereoscopically, so to speak, at many ideas which otherwise I could only look at from one point (through one language), whence it would not be so easy, if it were possible, to see them in their true relative position. I have, therefore, made it a point to continue the acquirement of linguistic and philologic knowledge; I now speak five modern languages, and can read as many more, and I hope to speak ten and read twenty before I die. Such is the estimate which I place upon a knowledge of languages as a factor of mental training and equipment. I consider it second only to *good* mathematical training, and quite superior to *poor* mathematical training as a means of mental development. It has the advantage over mathematics of having less tendency to develop " abstractedness " of reasoning. I do not consider this as applying necessarily to all persons; I know many persons who cannot acquire languages, in spite of hard effort. I know others who acquire languages very easily. To me, languages have been useful in the same way as the abstract study of mathematics, to the extent that they tend to develop the intellect, increase the mental perspective and broaden the intellectual horizon, and also, besides, to the extent that they are of practical utility for the purposes and in the way very ably pointed out by Mr. Pearson. I stand with him firmly on the ground which he takes, that no engineer who ever expects to fill an important position in the world—especially one who aspires to international reputation—should neglect the study of languages. I consider a knowledge of French and German just as important a part of a man's intellectual equipment as any of the other studies.

If I had any suggestion to make in connection with the teaching of languages, it would be that the study of languages be put at the very beginning of the curriculum, or, indeed, that it should precede the technical curriculum.

We all know that the acquirement of a foreign language, which is relatively easy in youth, becomes more difficult as age advances. The early study of a foreign language, therefore, is desirable, because the task of acquiring the language is thereby simplified. It is also desirable for another and still more important reason, namely, because of the importance of language as a means of mental development and discipline. It cannot be denied that the study of foreign languages, as well as the study of the classics, during youth, has a powerful effect in teaching the mind how to assort, assimilate and assemble ideas, and especially how to differentiate shades of meaning. Now, when a person begins to distinguish between shades of meaning, he must have learned, or he is learning, to differentiate between shades of thought, and that is a step of the highest importance and value in technical training. It is for this reason that the study of foreign languages is regarded by many as an important course in the art of clear thought and clear expression.

I now come to the question of mathematical training, which is in my opinion, one of paramount importance. I agree, substantially, with Mr. Steinmetz in regard to the amount of mathematics which should be included in an engineering course. I am a partisan of mathematical knowledge as an important item of the engineer's professional equipment. I believe strongly in both *quantity* and *quality* of mathematical knowledge; but when both cannot be conveniently had, I am strongly in favor of sacrificing quantity for quality. In this connection I wish to remove the onus which is wrongfully placed upon the men who actually educate the electrical engineer. The professor of electrical engineering has, so to speak, " caught it " rather hard, and, in my opinion, most undeservedly; he has been held responsible for many failures in turning out competent "engineers," which ought properly to be credited to some of his colleagues in the faculty—notably the professor of mathematics. The truth is that the mathematical preparation of the students is, in a large number of cases, quite incomplete and inadequate. That is why they stumble in the analytical and applied mathematical studies. Dr. Perrine's allusion to the course in differential equations, which he had such difficulty in arranging, is an interesting revelation. As the result of extended observation, and of the confidences of many engineers and students during the last fifteen years, I have come to the conclusion that much of the deficiency in engineering education, both theoretical and practical, is due to the difficulties which are *made* instead of *removed* for technical students, by their teachers in mathematics. I have begun to look upon mathematics, both pure and applied, as taught by many college professors, as a means of befogging the pupil, of obscuring his mind, of literally putting difficulties in his way, instead of enlightening him and facilitating his progress, as should be the case with proper teaching. I have two nephews now following engineering courses. I found that both had difficulty in keeping up with the course in calculus. I undertook to help one of them at his request. I found that he lacked knowledge of the fundamental preliminary principles forming the groundwork of the subject; it was like trying to learn square root before learning multiplication or division. When I inquired whether these things had not been taught him and why they had not been learned, even before entering upon this study, I learned that the young man, in common with the great majority of his class, had been groping and stumbling in the dark during the entire term. Only a few of the students were still pretending to follow the professor, who had been, all this time, to use their own words, " talking to himself and over our heads." The professor had evidently done his best to " keep ahead " of the students, and he had run no danger of being overtaken. The young man naturally had " mathematical indigestion," in rather aggravated form, as the result of trying, for weeks, to gorge his mind by main strength of memory, with undigested mathematical " pottage."

As pointed out in the Presidential address, by Mr. Steinmetz, (who may well be deemed an authority on subjects mathematical) the memory will not retain formulæ which the mind has not *analyzed* and *understood*. I took advantage of a vacation week to give the young man a new start, by going back with him to the very beginning, and laying a solid foundation of *elementary* *fundamental* knowledge. The difficulties complained of vanished quickly, and the young man then made satisfactory progress. His natural ability is such as to force upon me the conclusion that his deficiency was entirely due to inadequate teaching.

Quite recently, I had occasion to help another young man, who is a recent graduate of a well-known technical school, to take a fresh start in some of his mathematical studies, including calculus. He also had been a sufferer from the same kind of indigestion, pretty much for the same reason. I could cite at least a dozen similar cases; and in all of them I really blame the teacher more than the pupil. It is a well-known fact that the percentage of graduates who retain sufficient interest in their mathematics to care to keep up their knowledge and increase it, after leaving school, is extremely small. The great majority proceed to " forget it " with a rapidity which almost savors of alacrity; and, in come cases, they become empirical to an extent which makes even a non-graduate " practical " engineer blush. What is the cause? *Mathematical dyspepsia.* The mathematical " indigestion " from which the students suffered for four years, while in college, has become chronic—it has become " dyspepsia," and mathematics are no longer palatable because " they never did agree with him." He literally, and to use his own words, " has had already more than he wants of it." He therefore falls into " practical " ways, and is fortunate if he does not evolute to the point of wondering what mathematics were ever invented for, anyhow.

Having had to teach myself mathematics (beyond the mathematics acquired in a high school course), and being a rather poor pupil, I needed very patient and somewhat scientific teaching. That is why I have given so much attention to the study of methods of teaching. I still am engaged in the study, both as the pupil and his teacher. Mathematics are a part of my " post-graduate work," and I find it interesting and profitable to devote many hours of leisure to them. I have had occasion to help others to get knowledge of the subject, and I have discussed the matter of teaching mathematics with many teachers, among whom I will mention Dr. John Perry of the Royal Technical College, London, whose name stands among the foremost in electrical science and in engineering, and stands in the very front rank as a mathematician and a teacher of mathematics. During the visit of our INSTITUTE to England in 1900, it was my pleasure to meet Dr. Perry on many occasions (he then being President of the Institution of Electrical Engineers), and to study him as a man, as a scholar and as a teacher; and, in common with all the American members of this INSTITUTE who were guests of the Institution of Electrical Engineers, I learned to admire and esteem him greatly. I had occasion to discuss with him the subject of teaching mathematics, both from the standpoint of pupil and teacher (both sides being interesting to me for the reason already stated); and I was very much pleased and encouraged by what I considered his very sensible views on the subject. He was the first mathematical teacher that I had met who had enough imagination and judgment to put himself in the pupil's place, and to properly appreciate the pupil's difficulties and note his needs. I found with pleasure that he had been for some time preaching reform in methods of teaching mathematics in England. He had found as the result of extended experience as a teacher, that only few mathematicians are " born "; that the others have to be " made "; that the present methods of " making " them were not fully satisfactory, and might be greatly improved. He gave me a copy of his " Practical Mathematics,"—a summary of six lectures delivered to workingmen," and I would recommend every engineer, and even every teacher, to procure and read these lectures. I read the book on the steamer, and found it so good, that after I arrived, I procured a half-dozen copies, which I sent to various friends who, I knew, would be grateful for light on the subjects discussed by Dr. Perry.

At the last engineering congress, at Glasgow, in 1901, Dr. Perry read a paper on the teaching of mathematics, which I also recommend to every man who has had to struggle to get light on that subject, whether he has been through a university or not. This paper formed the nucleus or the starting point of an interesting discussion, constituting an able symposium, in which the ablest mathematical men in England, from Lord Kelvin down, took part; hence it is not the expression of a few desultory or sporadic thoughts on the subject, but it represents the entire analysis of the question of teaching mathematics. You will find that the conservative teachers, " the Euclidians," do not hit Prof. Perry very hard, notwithstanding the extremely radical views which he took on the subject. I also recommend Dr. Perry's presidential address before the Institution of Electrical Engineers as most profitable and wholesome reading for engineers. It seems to me that many mathematical authors especially in America, write their books, same as some professors lecture, for an " audience " of professors and critics rather than of students. The mathematical professor should use his knowledge to *impart knowledge* to his pupils. He too often uses it to *impress them with it*, merely. In discussing methods of teaching with some of them—not of Dr. Perry's kind but of the old-fashioned kind—I have been surprised to see the importance which they ascribe to the adjectives *terse* and *rigorous*. Many of them apparently think that they lose dignity unless they are strictly " terse and rigorous." Because, figuratively speaking, they themselves can clear almost any obstacles with a stride or a jump, they assume that the poor student ought, can and must do the same. The student, therefore, finds himself, in most cases, just as much handicapped as if he were trying to keep up with a fleet-footed runner, who is also a good, all-around and well-trained athlete. When the steps of the reasoning are too large for the mental grasp of the pupil, he memorizes them without understanding them, which means that he does not really learn the reasoning but takes it for granted. In such a case, mathematical study does not strengthen and discipline the mind, but does the very reverse. If, on the other hand, the pupil were led over a less steep and precipitous path, even though it were apparently a much longer path, he would not be so likely to lose courage or lack confidence in himself or his teacher, and, as I have found repeatedly, he would attain the goal more often, with less effort, and in less time, than he does by the orthodox " terse and rigorous " route. In this case the student, being able to see the steps without difficulty, can use judgment, instead of trying to rely wholly on memory, in following the road. His reasoning faculties are exercised and trained without straining the memory—which is, in my opinion, the most satisfactory method.

While it is true that there is no royal road to mathematical knowledge, it is certainly a great mistake, in my opinion, to imagine that the best road is along the line of maximum effort. I believe, on the contrary, that the best road lies along the line of least effort. I am not in sympathy with the idea of some teachers that it is necessary to make a thing difficult in order to have it well learned and remembered. We begin the physical training of children by light gymnastic exercises, not by physical efforts which would strain the athlete The same rule should apply, *a fortiori*, in intellectual training, for the important physiological reason already noted, namely, that mental growth is essentially a slow process, which should never be forced. The intellectual gymnastics should be such as involve the least mental *effort*, and produce the most intellectual *exercise*. One orthodox teacher of mathematics argued that the teaching should not go so far in elucidation, as to literally " put the dot on the i " for the student; I agreed; but I insisted that the pupil should nevertheless be taught that there *is* a dot, and where it ought to be put on that i, instead of being allowed to guess it. In this connection I wish to call attention to the striking contrast between French and American mathematical text-books. The French mathematical teacher believes in the " rigorous " just as much as his American colleague, but he has no sympathy for the " terseness " which is secured at the expense of *lucidity* and *intelligibility*. He does not hesitate to devote pages, sometimes, to the elucidation of topics which the American text-book treats " tersely " in a short paragraph. He follows the line of least effort. His book is more bulky, but it is far more easy to " digest " than the American text-book. Instead of being a cause of intellectual dyspepsia, it is, on the contrary, a prophylatic and a cure for it. Instead of destroying the taste and aptitude for mathematical study, it stimulates and develops them. I would advise all science students to study and master the French language, if only for the assistance which it will place at their disposal in their studies in pure and applied mathematics. There are many

American teachers, especially among those who write text-books, who could profit by the same advice. A few of them have already done it, or are doing it, I am glad to say, and it is to be hoped that their study of books, such, for instance, as Briot's admirable text-books of "lessons," (in algebra, trigonometry, analytical geometry, etc.), which have run through fifteen or more editions, may inspire some ideas of reform in methods of teaching. It may be a mere accident or coincidence, but the fact is interesting, that by far the most thoroughly trained and able young graduate engineers in a mathematical sense, whom I have ever had in my employ, were the product of French methods of teaching and of French schools.

In concluding this portion of the discussion, I wish to express the opinion that Dr. John Perry deserves the applause and the gratitude of all who believe in mathematics, for the crusade of reform in methods of teaching which he has inaugurated. His recognized mathematical learning and scholarship, his international reputation as a scientist, his writings, his lectures, and above all, his long personal experience in teaching pure and applied mathematics, make him a most competent and authoritative judge and critic of methods of teaching mathematics. His opinion to the effect that reform is needed, may well be accepted as conclusive evidence that *it is* needed.

Dr. Perry will, I hope, forgive me for betraying his confidence, as I am now about to do, to the extent of disclosing some of the " details " of his method or " art " of teaching, which are quite pertinent to this discussion, and which show, incidentally, that he can teach other things than mathematics and engineering, and with success. Reference is made in some of the papers, especially in Dr. Sheldon's paper, to the importance of developing or disciplining the emotional and æsthetic sides of the student's nature. Dr. Perry also lays great stress on the cultivation of the higher mental attributes, more especially the *imagination*, the development of which he deems of great importance as a factor of the student's progress in his studies and his success in technical work. He informed me that he studies carefully the pyschology of each of his pupils, and when he finds the imagination deficient, he proceeds to apply a " stimulant " in the form of non-technical general reading. He showed me, in his study, at the Royal College, a well-stocked library, which he has gathered together almost for that express purpose. In some cases he may " prescribe " and " administer " poetry, in others, history, general literature, travels, romance and adventure, according to the " case." I was surprised to find Cooper's novels, and most of our standard classical American novels, in his lists of authors. I was also surprised and gratified to note Dr. Perry's wide knowledge of our literature; but I was still more surprised at the scientific manner in which he used it as a stimulant for the imagination, and as a " developer " of the student's broader culture. He related numerous cases, giving the " diagnosis " and the "treatment" and the gratifying results accomplished. He cited cases where a "cure" or, at least, great improvement was effected by the perusal of a few stirring novels and an occasionally friendly "talk." His pupils all admit that he is a great and successful teacher, who has the rare faculty of retaining the attention and keeping up the interest of the students, and of infusing individuality into them. It is my opinion that Dr. Perry could teach many teachers valuable lessons in the *art of teaching.*

Before concluding, I wish to applaud heartily and to emphasize strongly the pertinent, well-deserved criticism made by Mr. Pearson, to the effect that the present methods of education are apparently too sordid, and aim too much at the *immediate* result, and too little at the *ultimate* results. The schools may not be altogether to blame for this. Prof. Esty distinctly advocates the kind of technical education "which aims not to make the graduate immediately successful in commercial life, but aims rather at ultimate success." Doubtless many of his colleagues hold or would like to hold this broader view, but the public, the parent and the student do not, unfortunately, take this broad view, and they have created a "demand" for the "other kind" of education. In justice, we must admit that it is they, and not the schools or the teachers, who are "sordid." They too often consider engineering to be a "business" instead of a vocation. The student is too often the raw material from which his parents, friends and advisers want the professor to turn out, not an engineer, but a wage-earner. The young man has chosen this or that branch of engineering, not because he really deems himself most apt and fitted for it, but because "there's money in it." In other words, the end in view is *dollars*, as many and as quickly as possible, rather than what it ought to be, namely, *attainments* primarily, and *emoluments* secondarily. This is only a very natural propensity perhaps, in the age and in the land of the "mighty dollar." Like Mr. Pearson, I do not admire this propensity, even though it be growing in "popularity." It demoralizes the scientific spirit, and tends to lower the standard of professional ethics. I am often asked by young men, just out of technical schools, what is the best thing for them to do, or what is the best way for them to "start." I have always made it a point to begin the answer to their questions by asking them questions, such as: "Do you wish to go *quickly* or to go *high*? What is your ultimate object in this 'business?' Do you merely want to become a hundred-dollars-a-month man or so, or do you wish to attain the pitch, the standing, the value, call it the "earning capacity," if you will, of a thousand-dollars-a-month-man? The young man generally admits that he would rather join the one thousand dollar class; but when I explain to him the laborious process, and point out the long tedious roads which have to be followed in order to become qualified for that class, he very often becomes discouraged, and concludes that he will take the short cut route, and trust to " luck " or " business ability " to get above the $100 class. The truth is, that in qualifying for the $1,000 a month class, he must spend more years in training " *at both ends of his course* " *i. e.*, both after and before graduation; in other words, he must *broaden*, *deepen* and *strengthen* his education in every way possible. He must not expect immediate results; he must not start with the notion that he is at once so valuable to his employer; but he must spend years and years building the foundation, acquiring practical knowledge, acquiring theoretical knowledge, fortifying and consolidating theory by practice, and solidifying his theoretical knowledge, developing the qualities of individuality, originality and resource, until he is able to grasp difficult, intricate problems, and handle them with little or no difficulty. This means years of application and effort.

There is a valuable suggestion in Mr. Raymond's paper, in the statement that " the college graduates should consider that the knowledge gained at the university is only a start and not a suggestion of a finish." Every graduate ought to feel that as he leaves school he is entering upon a " post-graduate course," which is to last the rest of his useful life. I have been following such a course for the last twenty years, and I hope it may last twenty or thirty years longer.

I have confirmed by repeated observation the truth of Dr. Goldsborough's remark about the applicant for a position. The individual often spends too much effort in trying to get a position and too little effort in trying to keep it. I think it far better to spend time, even years, in getting ready to *fill* a good position than in seeking for it. The old proverb says: " He who deserves success shall command it." The engineers who are successful, (I mean as engineers, not necessarily as money-makers), carry out, as a rule, the spirit of that proverb; they symbolize its realization. They typify and dignify the doctrine that the " position should seek the man." They bestow their best efforts upon all their work, whether the task be imposing or humble. They are content to do little things long, until they can do them well, and to learn through them, and to progress from them to greater things. The time ultimately comes when they can utilize their knowledge to advantage and with financial profit; and oftentimes the longer the opportunity has been in coming, the better and more satisfactory it proves to be. Luck has far less and merit far more, to do with these things than is generally believed. Just as, in physics, water proverbially seeks and finds its level, so in human affairs, there is a force tending ever to place individuals at the proper levels. Shakespeare has expressed this force in terms of a " divinity which shapes our ends." Reverting again to Victor Hugo's quaint phrase, I would state that our " ends " are " shaped," oftentimes, not " because of " but " in spite of " our efforts to " rough hew them as we will." We often find the man whose object was pelf, fail to get that which was his sole object, whereas the individual whose primary aims are merit and worth, often " gets the emolument besides."

In conclusion, I may say that I am highly impressed by the general programme of " reformed " engineering education outlined in Prof. Esty's paper, in the concluding paragraph. I am also glad to find some authoritative expressions of sentiment favoring better and broader preliminary general education, more thorough even if less extended theoretical and practical technical training, and in general, commending the process which leads to the best ultimate rather than to the most immediate results.

MR. SKINNER:—As a representative of the engineering department of a large manufacturing concern, I wish to agree most heartily with all that has been said in favor of the broad education of the engineer. I fully appreciate the difficulty mentioned by Prof. Goldsborough, that many students, particularly in the West, are, for financial reasons, unable to continue their studies for the length of time necessary to get this broad education. I am surprised, to say the least, at the grounds taken by Mr. Raymond, that specialization should begin so early. I think we are all more or less familiar with the phenomenon of the aging of steel after it is annealed. I am sure that men with such training as Mr. Raymond advocates will age very rapidly, indeed, when put through his annealing process.

PRESIDENT STEINMETZ:—Gentlemen, discussion is still in order. I call upon Mr. R. W. Pope, who was going to give a few minutes' talk.

SECRETARY POPE:—I just wish to say that I have not sufficient command of language to express my appreciation of the attendance here, and what the people of my native town have done for the engineers, and the fact that we have been brought together under such delightful circumstances. I obtained Mr. Arnold's permission before he left, to join me in support of Mr. Mailloux's argument that we could not learn too many languages, and if there is one thing that Mr. Arnold and I regretted, it was that we knew so little of French when we were together in Paris.

In my school days, which with the exception of one year were passed in Great Barrington, a college education was scarcely thought of unless the pupil intended entering the profession of law, medicine or the ministry. My school education ended with my fourteenth year. I have always regretted that this was the case, as I now realize that there must be a feeling of satisfaction due to college training that has been lacking in my own experience. I have, however, trained myself to believe that the education of a man is a most important step in his career, but that the result depends very largely upon the quality of the material to be dealt with. It has been stated in this discussion that the profession of electrical engineering dates back only about fifteen years, and I have therefore thought it of interest to include in my remarks an editorial written by me seventeen years ago which appeared in the *Electrician and Electrical Engineer*, October, 1884, as indicating the views of one who at that time had been engaged in railroad and telegraph work twenty-five years.

TECHNICAL EDUCATION.

"There is no more important question in the whole range of social topics than that of education, and public attention has been directed to it both in Europe and America, for the purpose of devising, if possible, some system which would more effectually teach what the pupil may be expected to practice when he reaches maturity. The fact that a student when obtaining a classical education devotes to that work the very years when he should be gaining a practical knowledge of the handicraft by which his living must be earned, has in a measure, obliterated the old idea that every boy with brains *ought* to go through college. The value of such a training is by no means to be underrated, but it should not be exacted without proper consideration of the future, and every parent should be able to discern whether a boy of fourteen has a decided leaning toward the so-called learned professions, science or mechanics. Whatever walk in life he may finally travel, he may not prove eminently successful, even if meritorious. Success, from a worldly point of view, is a matter of chance, as well as of merit; but moderate success, which brings contentment and happiness to thousands of humble homes, is but the application of honest industry and judicious economy to that line of duty which has finally been selected as the means of livelihood. This is the fundamental idea of a technical education. To what extent it should be carried out is still a matter of dispute. There can be, however, no good reason advanced why a bricklayer may not graduate from his special school, as well as a physician from a medical college. Practically the artisan would be the more perfect production of the two, for the reason that the elements that he deals with do not present such a variety of phases which require far more practical experience. In discussing the merits of technical schools, both their opponents and advocates are prone to lose sight of the value of experience. The amateur artisan, as well as the college graduate, in cutting loose from their Alma Mater enter the professional arena, and instead of humbly seeking further light as to the mysteries of their craft, endeavor to parade their superior attainments, get snubbed for their pains, and at once build up a feeling of enmity which years of association may not eradicate. The student should be constantly impressed with the idea that he is not *learning* a trade or profession, but merely learning how to begin, and then when he enters the vast field of labor, it will be in the more dignified garb of a skillful apprentice, rather than that of a bungling journeyman. He will thus escape much of the drudgery which usually falls to the lot of the youngest employes, for the reason that his time will be too valuable to be devoted to such service. Here it may be remarked that much of the animosity that exists against the introduction of new labor in the trades, is caused by the placing of incompetent hands, at low wages, in positions which they are not qualified to fill. Employers are also responsible for the existence of considerable ill-feeling, by not properly appreciating the value of long experience in certain branches of the service. A larger proportion of the spirit of humanity infused into those years of toil would, beyond question, materially increase the profits of nearly every branch of business."

In re-reading the above under the light of later experience, and in view of to-day's discussion, I will merely add that I take pleasure in admitting the advantages and satisfaction to be derived from a classical education, supplemented as far as possible with a knowledge of modern language, in which I should certainly include French, German and Spanish. My experience teaches me that the student should pursue his studies as early as possible, for unless he denies himself the opportunities offered for recreation and social intercourse, he will find that owing to the demands upon his energy required in his regular employment, he will find less and less opportunity to study. My early telegraphic work, followed by years of editorial experience, and accompanied at all times with reading of the best English literature, has forced upon me what little knowledge of our language I possess, and at the same time taught me that a more thorough general education would have established a more satisfactory foundation, which I would urgently advise young men to obtain, and the neglect of which is to-day inexcusable.

MR. RAYMOND:—I think the paper has had an injustice done it. These gentlemen apparently assume that as soon as men graduate from college that all study ceases. I propose to drop during the college course those studies that will be taken up by the students themselves later, such as literature and history. A man can read history without a trained professor to assist him. One who has come out of college and has studied for four years is not going to stop as soon as he graduates. It would undoubtedly be interesting to study astronomy during the college course, but we must agree there is no time to take it up. Many of us since leaving college, may, however, have studied it quite thoroughly. I repeat, why not drop the studies that can easily be taken up after graduation and concentrate on those most urgently needed in our profession and in a large number of cases not properly taken up during the college course.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF PAPER BY M. LEBLANC.]

The result of M. Leblanc's paper can be obtained in a very simple way by directly considering the case of a transmission line having no ohmic resistance but only distributed capacity and self-induction. I will briefly outline how to obtain this result, leaving to a special paper the highly interesting subject of the phenomena of long transmission lines treated in an elementary way.

The differential equation for a long transmission line having distributed capacity and distributed self-induction is readily obtained from our figure. Let C be the mutual capacity per unit length, and L the inductance per unit length of the two wires, then the charging current per unit length is

$$i = 2 \pi n C v \qquad (1)$$

where v is the potential between the wires. Setting $2 \pi n C = a$, for the sake of simplicity, we have

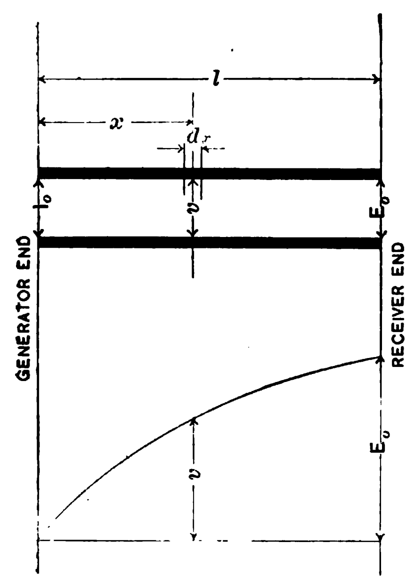

FIG 1.

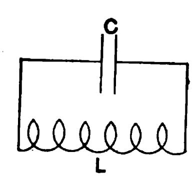

FIG. 2.

$$i = a v \qquad (2)$$

The e.m.f. of self-induction is equal to

$$e = 2 \pi n L i \qquad (3)$$

Again, setting $2 \pi n L = b$, we obtain

$$e = b i \qquad (4)$$

Let us investigate the distribution of potential along the line on the supposition that the potential at the generating end is zero, then the distribution of potential thus obtained will be identical with the distribution for the fundamental of the natural vibration of the line.

We have for the charging current in the element $d\,x$.

$$di = a\,v\,d\,x \tag{5}$$

The inductive drop in the line is

$$dv = -\,b\,\imath\,d\,x \tag{6}$$

Hence, by differentiating (6) and substituting in (5) we obtain,

$$\frac{d^2 v}{d\,x^2} = -\,ab\,v \tag{7}$$

The solution of this equation is

$v = A \sin \kappa\,x + B \cos \kappa\,x$, for by differentiating

$$\frac{dv}{dx} = \kappa\,A \cos \kappa\,x - \kappa\,B \sin \kappa\,x$$

$$\frac{d^2 v}{d\,x^2} = -\,\kappa^2\,A \sin \kappa\,x - \kappa^2\,B \cos \kappa\,x$$

$$\frac{d^2 v}{d\,x^2} = -\,\kappa^2\,v$$

Therefore, $\kappa^2 = ab$, and $\kappa = \sqrt{ab}$ (8)

For $x = 0$, $v = 0$, by our assumption, hence

$$A \sin \kappa\,x = -\,B \cos \kappa\,x$$

$$B = 0$$

Therefore,

$$v = A \sin \kappa\,x\,.$$

For $x = l$, $v = E_0$, hence

$$E_0 = A$$

The potential at different points of the line is thus given by the equation,

$$v = E_0 \sin \kappa\,x \tag{8}$$

We obtain the maximum value of v for

$$\sin \kappa\,x = 1,$$

and, therefore, the most dangerous case exists for a line whose length is such that

$$\kappa l = \frac{\pi}{2}$$

or, substituting for κ its value $\sqrt{ab} = 2\pi n \sqrt{LC}$, we obtain

$$l = \frac{1}{4 n \sqrt{LC}} \tag{9}$$

Now, let us see what relation the length of the line thus determined has to the wave-length. It can easily be proved that the velocity of an electro-magnetic disturbance is given by

$$V = \frac{1}{\sqrt{LC}} \tag{10}$$

L and C being the inductance and capacity per unit length of the line in electro-magnetic measure.

Let λ be the wave-length, then we have

$$\lambda = \frac{V}{n} = \frac{1}{n \sqrt{LC}} \tag{11}$$

and substituting in (9)

$$l = \frac{\lambda}{4} \tag{12}$$

which is M. Leblanc's result arrived at in a strictly correct but simple manner.

I need hardly remark that from equation (8) follows that if κl is equal to $3\pi/2$, $5\pi/2$, $7\pi/2$, etc., a dangerous state is obtained.

From (9) follows that the fundamental of the natural frequency of the line oscillation is

$$n = \frac{1}{4 l \sqrt{LC}} \tag{13}$$

It is interesting to compare this result with that of a condenser and an inductance connected in series. The natural frequency of such a system (Fig. 2) can easily be obtained by the consideration that the potential difference between the condenser plates must be equal and opposite to that at the terminals of the inductance, hence

$$2\pi n L i = \frac{i}{2\pi n C}$$

From this follows:

$$n = \frac{1}{2\pi \sqrt{L C}} \tag{14}$$

The discharge frequency of a long line with distributed capacity and self-induction is therefore greater than if the capacity and self-induction were concentrated as in Fig. 2.

The subject is treated by Dr. Bedell and Dr. Crehore, and by Mr. Steinmetz, and my remarks are made with the sole purpose of showing a short cut to the known results.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF MR. STEINMETZ'S PAPER ON THE "THEORY OF THE SYNCHRONOUS MOTOR."

Mr. Steinmetz calls the quantity $\frac{1}{2} m v^2$ by the name of "mechanical momentum," but since the time of Newton the term "momentum" has been used to designate the product $m v$, and we speak of the "conservation of momentum," and of the "conservation of angular momentum," meaning thereby the conservation of the product $m v$, as, for instance, in the case of impact. Since the formulation of the principle of the "conservation of energy," we have been accustomed to call the quantity $\frac{1}{2} m v^2$ the "kinetic energy" of the body in motion, and we should like to ask why Mr. Steinmetz deems it necessary to change, without explanation, a nomenclature which has been used by Helmholtz, Kelvin, Maxwell, Rayleigh and others.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY MR. CALVERT TOWNLEY IN DISCUSSION OF MR. A. H. ARMSTRONG'S PAPER, PAGE 809.]

I have read with much interest Mr. Armstrong's account of his various investigations, which involve and represent an enormous mass of painstaking mathematical calculations. His graphic representations of the results obtained are clear and concise, and will furnish material for much contemplation and study to any one interested in following out the possibilities involved by changing the numerous railway motor variables between widely separated limits.

His individual conclusions given as interpreting the various curves plotted are clear and well stated, but there is one general conclusion not deduced directly from the calculations which does not seem to me proved, and with which I am unable to entirely agree. Mr. Armstrong states:

"As a result of considerable investigation along these lines, the writer has not arrived at any commercial rating of a railway motor which serves its purpose better than the one-hour test now universally used. Admitting that such a test does not give the comparative size of different motors, it does serve the purpose of largely determining its commutating qualities and possesses the advantage of being commercial. Unless a rating can be proposed which will indicate accurately the relative size of motors, the present method of one-hour rating possesses advantages which would hardly warrant its being superseded."

Summing up briefly, the plotted results of the calculations show that there are some thirteen or more variables which affect the service capacity of a motor, that there is no short-cut method of rating a motor which takes into account all these variables, the inference being, therefore, that neglecting so to do is likely to lead to fatally erroneous conclusions. In the face of this set of conditions it is not clear to me what can justify the one-hour horse-power basis of rating motors which takes account of practically none of these variables. The advantages of the one-hour horse-power rating of motors are stated as follows:

"It does determine the mechanical qualities of the motor, as the one-hour test is generally very severe, and it also affords a means of observing commutation at the maximum current for which the motor will probably be called upon in service operation."

It is not clear to me what is meant by the "mechanical qualities" of the motor. This term cannot refer to the mechanical strength of the various parts of the motor, as the mechanical strains in a shop test of this nature are of course very light compared to the strains of service. The fact that a motor, resting on a stand in the shop, would take a certain amount of current for an hour, would hardly be held as any measure of its mechanical strength for its service on a road.

With reference to commutation, the comparison is hardly less decisive, as a modern commercial motor which did not at least commutate well on towards twice the current represented by its one-hour horse-power rating would hardly find much favor. There are two other reasons, not given in the paper under discussion, but sometimes advanced for the retention of the one-hour horse-power rating; first, that it is an established basis of comparison broadly known and used by railway men, and second, that the use of the term horse-power affords the advantage of a well-understood unit which is comprehensible alike to engineers and laymen. The first of these reasons is sound so far as it goes, but the same reason is always offered against any change in standards or nomenclature, and is scarcely sufficient for adhering to a method otherwise undesirable. The second reason has always appeared to me an argument against itself; *i.e.*, that the very use of the word "horse-power" as applied to a one-hour rating is misleading, in view of the fact that this term is broadly associated with the capacity of apparatus in continuous service. I well remember the strongly expressed disappointment and disgust of a prominent railway official who had been talking about the "horse-power" of railway motors, when he learned that the term meant capacity for one hour only, whereas he operated his lines twenty-four hours a day. If there is a good reason for adhering to the term "horse-power," it might better be applied to a rating corresponding to the duty which the motor would perform continuously.

In the light of all of the foregoing, a plea for the retention of the one-hour horse-power rating would seem to ask that as we cannot get a short-cut rating which will express with absolute theoretical accuracy all of the comparative features of two or more motors, let us use one which is as inaccurate as possible.

It is undoubtedly true that the increase in maximum and in schedule speeds, and also in the weight and amount of heavy traffic, which has been perhaps the most prominent feature of recent developments in electric traction, tends to aggravate the inaccuracies of short-cut comparison pointed out in this paper, and no one will gainsay the desirability of determining the adaptability of any particular motor to the service requirements for any particular installation with all the accuracy that is practicable, and is justified by the magnitude of the enterprise. In recognizing these facts, however, we should not forget that a very large proportion of the money which is invested in railway motors is by roads operating equipments of small or moderate capacity, operated at low or moderate speeds. For such roads it is frequently, one might almost say, generally impracticable to determine within accurate limits the service conditions described by this paper as necessary for the proper comparison of motors. It would, therefore, seem reasonable to determine within what limits a conclusion based on some short-cut method is likely to err, and in our methods to allow such a margin as will minimize the chances of any serious misfits It will hardly be disputed that if we cannot be absolutely accurate we should be as accurate as we can, and I for one should regard it as unfortunate should this INSTITUTE appear to the public committed to the statement that it is ordinarily impracticable to select a railway motor suitable to average service conditions without making a somewhat intricate comparison based on service data which it is impossible to obtain.

In this connection, the method of rating and comparing the service capacities of motors as proposed by Mr. N. W. Storer in articles entitled "The Capacity and Rating of Railway Motors," printed in the November 2, 1901, and January 5, 1902, issues of the *Street Railway Journal*, appeals to me as coming much nearer a useful method than the one-hour horse-power rating. The writer has had occasion to check the type of motor indicated by this method as best, with that shown most desirable by more intricate calculations obtained at considerable pains from service observations. In every case the motor selected by the Storer method has been a safe motor for the work, and very close in its characteristics to the calculated service conditions. On the other hand, instances are not lacking where selection on the basis of horse-power rating have produced results which were far from satisfactory. Be that as it may, however, I cannot but believe that the general sense of the members of this INSTITUTE is that if we cannot be absolutely accurate we should be as accurate as we can.

[COMMUNICATED AFTER ADJOURNMENT BY MR. PHILIP TORCHIO IN DISCUSSION OF THE REPORT OF COMMITTEE ON STANDARDIZATION.] [See page 1075.]

In connection with the "Report of the Committee on Standardization," I would like to make a communication calling attention to the paragraph where the recommendation of insulation voltage tests for fields of synchronous motors and converters is given as follows: "Synchronous motor fields and fields of converters started from the alternating current side—5,000 volts." It is my understanding that the Committee here recommends that *all synchronous motor fields* should be insulated for a test of 5,000 volts, but in the past some parties interested in this type of apparatus have intrepreted the recommendation of the Committee to apply only to synchronous motors *started from the alternating current side*. This point should be made clear so as to avoid misinterpretation. A statement reading "Fields of all synchronous motors and fields of converters started from the alternating current side—5,000 volts," would not be open to discussion.

It may now be too late for making any amendment to the report which has already been acted upon, but I make this suggestion for future consideration.

ASSOCIATE MEMBERS ELECTED AND TRANSFERRED.

Elected at Executive Committee Meeting, New York, July 25th, 1902.

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WETZLER, JEFFERSON,	Secretary and Treasurer, The Electrical Engineer Institute of Correspondence Instruction, 240 West 23d St., New York City.	Jos. Wetzler. W. D. Weaver T. C. Martin.

Total, 24.

TRANSFERRED TO MEMBERSHIP.

Recommended by Board of Examiners, July 2, 1902.

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JEREMIAH J. KENNEDY, Consulting Engineer, 52 Broadway, New York City.

GEORGE BROWN DUSINBERRE, Assistant to Fourth Vice-President, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Recommended by Board of Examiners, July 18, 1902.

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CECIL P. POOLE, Editor AMERICAN ELECTRICAN, 114 Liberty St., New York City.

JOHN FORREST KELLY, Consulting Electrical Engineer, Pittsfield, Mass.

Elected at Executive Committee Meeting, New York, Aug. 22, 1902.

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POMEROY, LEWIS, ROBERTS,	Special Representative Railway Department, General Electric Co., 44 Broad St., New York City; residence, East Orange, N. J.	E. H. Mullin. Eugene Griffin. J. R. Lovejoy.
REA, NORMAN LESLIE,	Student in testing Department, General Electric Co., Plattsburg; residence 222 S. Centre St., Schenectady, N. Y.	C. P. Steinmetz. E. B. Raymond. H. B. Dates.

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ROSENTHAL, LEON WALTER, Student Columbia University, residence, 203 W. 112th St., New York City.	F. B. Crocker. G. F. Sever. F. Townsend.
SOLOMON, NATHAN CLARENCE, Assistant Engineer, with Harry Alexander, 25 W. 33d St., residence, 522 W. 150th St., New York City.	Harry Alexander. Henry C. ter Meer. Hugh A. Brown.
STANTON, LEROY W., Superintendent of Equipment, The Federal Telephone Co.; 901 Electric Building, Cleveland, Ohio.	F. J. Dommerque. C. W. Holtzer. E. P. Roberts.
STOVER, RODERICK, Student, Columbia University, 519 W. 123d St., New York City; residence, Albuquerque, New Mexico.	F. B. Crocker. G. F. Sever. F. Townsend.
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