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A paper presented at the 224th Meeting of the American Institute of Electrical Engineers, New York, January 10, 1908.

A SINGLE-PHASE RAILWAY MOTOR.

BY E. F. ALEXANDERSON.

The various single-phase railway motors which have been developed during the past few years have been styled in general as either repulsion or as series motors.

The characteristics of the compensated series motor are well known; they comprise an armature, an exciting winding, and a compensating winding, usually all connected in series. One of the principle objections to this type of motor is the generation of an electromotive force in the coils of the armature which are short-circuited by brushes at the instant of commutation, due to the alternating character of the field. On this account this motor is limited to use on low terminal voltages.

The repulsion motor (invented by Elihu Thomson) has a short-circuited armature and a rotating flux. At speeds near synchronism the electromotive force of alternation in the short-circuited coils is counterbalanced by an electromotive force of rotation. The energy is introduced into the stationary winding and the motor can be wound for any desired voltage.

The most prominent types of single-phase railway motors which have found commercial application are:

1. The compensated repulsion motor (Latour-Winter-Eichberg). This motor has a short-circuited armature and an extra set of brushes for producing compensation, with a view to obtaining a higher power-factor.

2. The compensated series motor (Eickmeyer-Stanley-Lamme).

3. The compensated series motor with shunt-excited commutating poles (Milch-Richter). In this motor, a commutating field is produced locally by coils in the stator.

The motor to be discussed in this paper is neither a series nor a repulsion motor in the generally accepted sense, but embodies the best features of both. For lack of a better name it may be called a "series repulsion motor". The windings resemble those of a series motor, and the armature and stator are permanently connected in series. A general diagram of the motor is shown in Fig. 1. The terminal voltage of the series repulsion motor can be selected with greater liberty than in a series motor, but not so arbitrarily as in the case of a repulsion motor.

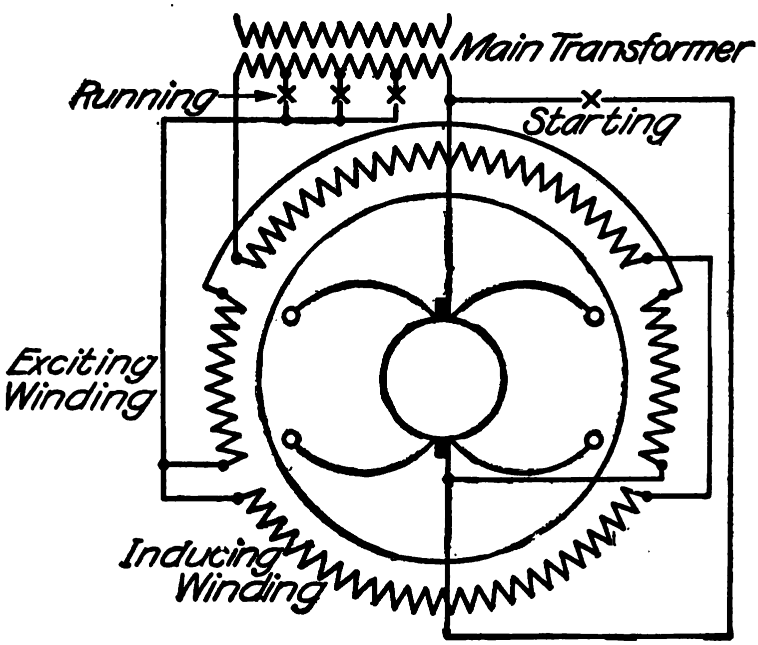


Fig. 1

Its advantages over the straight compensated series motor are very marked. The commutation is so radically improved that resistance leads are unnecessary and it is feasible to build the motors in larger capacities.

In its performance it resembles the series motors with commutating poles, but offers several distinct advantages over the same. Instead of producing a commutating flux locally by coils on the stator, the conductors in the armature are located in such places where the desired flux will naturally exist. This arrangement simplifies the stator winding considerably. The compensating winding of the series motor is replaced by an inducing winding with twice as many turns, and the energy is introduced either in the stator alone or in the stator and rotor together. By this arrangement, as will be explained later, the starting torque is doubled for the same commutation and the same supply of current.

In the compensated repulsion motor the commutating field becomes too strong as soon as the speed appreciably exceeds synchronism, unless special arrangements are made to suppress this field locally. The motor under consideration is not limited by the synchronous speed, as the repulsion motor feature is reduced at the high speeds, and its action follows more closely the performance of a series motor; the number of poles can therefore be selected with the same liberty as in a series motor. This is of great importance for the motor characteristics, particularly in regard to weight and starting torque. Furthermore, no extra set of brushes, nor any series transformer, is required, which makes the motor equally well adapted for direct and alternating current. These being the most important general characteristics of the motor, there are a number of features which are of interest, particularly to the designer. Before entering into these details it will be necessary to give the general theory of the repulsion motor, together with the general theory of commutation.

The pure repulsion motor has a rotating field, and it appears plausible that commutation may be good in a rotating field, provided the armature rotates at approximately the same speed as the field. However, a rotating field is not in itself a guarantee of good commutation.

When the field becomes ellipitical in shape, it is difficult to grasp the phenomena of commutation unless the field is resolved into its components and expressed as functions of time and space. If this is done, the following field components influence the commutation, as illustrated in Fig. 2.

A. The "main field", which is the torque-producing field, and corresponds to the field in a series motor.

B. The cross-field magnetized by an exciting current flowing in the armature, and serving to transfer the energy from rotor to stator. This field is in quadrature with the main field in time as well as space.

C. Another cross-field magnetized by the difference between the ampere-turns of the armature and the inducing winding. This field is in phase with the main field.

D. The leakage flux around the commutated coils.

The conditions for perfect commutation are as follows:

1. The electromotive force of alternation of the main field should be neutralized by the electromotive force of rotation in the cross-field designated "B".

2. The magnetomotive force of the stator should be larger than the armature reaction; the difference, which is the

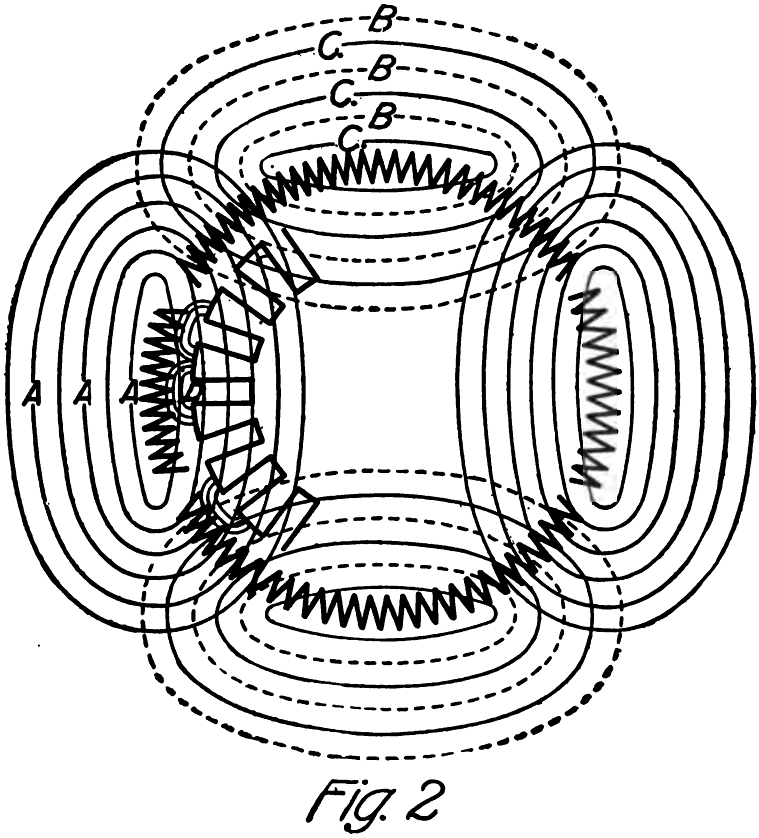


Fig. 2

field designated "C", should be large enough to overcome the voltage due to the leakage flux.

If these conditions are fulfilled, the commutation is identical with that of a direct-current motor with commutating poles.

The first condition is found at synchronous speed in a repulsion motor, and theoretically in a series motor at infinite speed.

In a series repulsion motor it can be obtained at any speed by varying the proportion between series and repulsion motor action.*

This, however, meets only one of the fundamental conditions necessary for good commutation; there are others which will affect commutation as much as will shifting the brushes of a direct-current motor from the right to the wrong side of the neutral.

The type of motor which is generally referred to as a repulsion

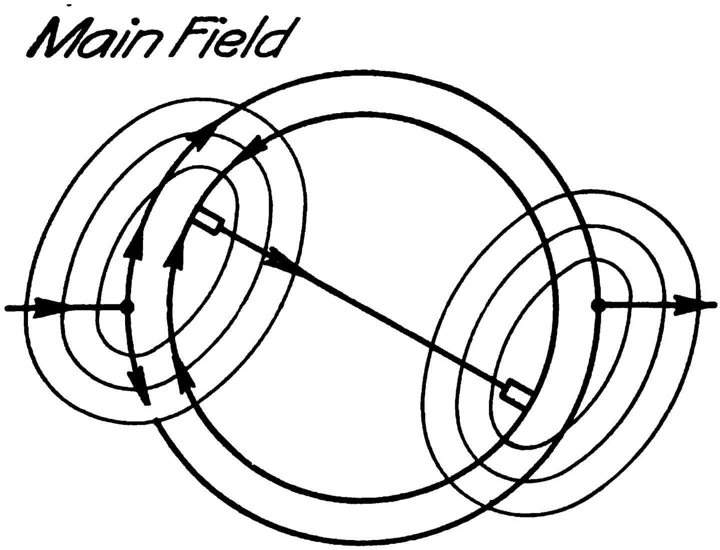


Fig. 3

motor is that with a continuous stator and rotor winding. and the brushes shifted in the direction of rotation as in Fig. 3.

If such a motor is used as a series motor with the stator and rotor connected in series, it is apparent from the diagram shown in Fig. 4 that that part of the windings which is included in the angle represented by the shift of the brushes constitutes the exciting coils, and the lines of force are distributed as shown on the diagram. The brushes are shifted in the direction of rotation and are located on the edge of the active field. It is well known

* Diagrams have been shown by Milch & Latour with a voltage impressed on the armature circuit in order to meet this condition.

in direct-current practice that the brushes of a motor ought to have a backward shift, if any, but never a forward shift: and it is therefore obvious, considering the direct-current features that this motor cannot commutate well. In the repulsion motor, the armature currents are induced by the transformer action, but the distribution of the currents is substantially the same as described above for the series motor. This difficulty has led to the design of an armature winding as shown on Fig. 5, by which the electromotive force due to the cutting of the active flux is eliminated. The magnetization is produced by a

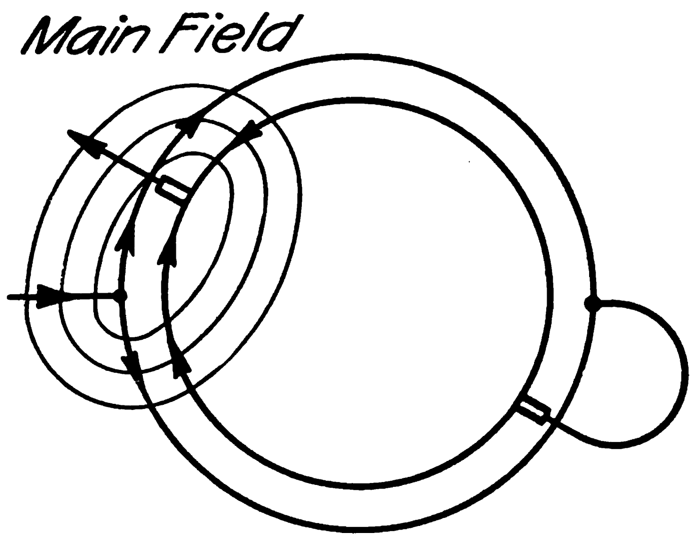


Fig. 4

separate stator winding located symmetrically with respect to the brushes. This gives a distribution of the fields as shown in Fig. 5. The armature conductors under commutation are located on the edge of the field flux, so that both sides of the coil are under an equal flux of the same polarity.

There is another way of looking at this phenomenon which leads to the same result: the winding of the repulsion motor can be separated into an exciting winding and an inducing winding, in this case the brushes are located in the neutral of the stator winding. The armature is the short-circuited secondary of the inducing winding and must consequently have substantially the same total number of ampere-turns. The two fields that are excited by the stator and rotor individually are shown in Fig. 6 (*a*). The rotor field is peaked and stator field is flat-topped, giving a resulting field as shown by the cross-section part of the diagram. Consequently, there is a resulting peaked field opposite to the brushes where the conductors under commutation are located. This field is excited by the armature and has all the detrimental effects of armature reaction. Fig. 6 (*b*) shows how this is overcome by a fractional pitch winding on the

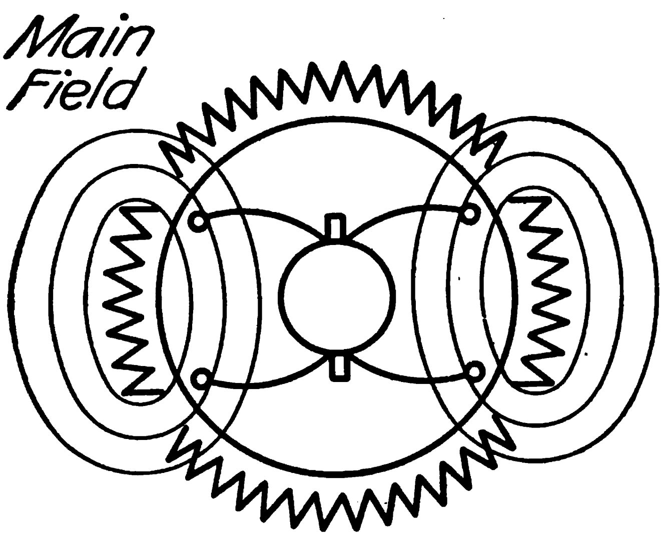
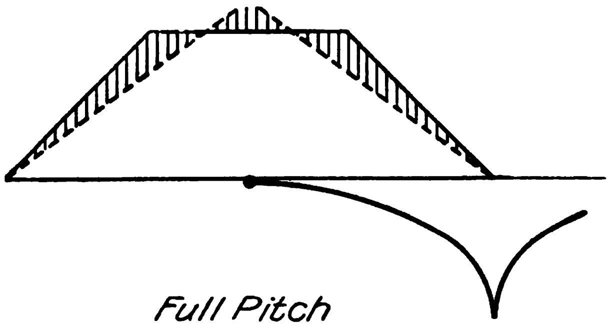


Fig. 5

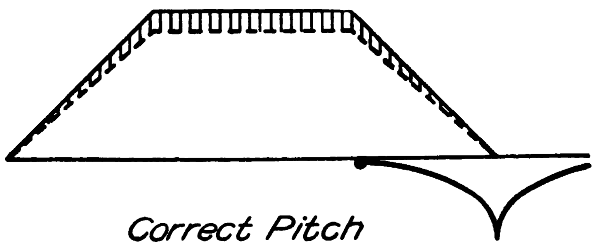
armature. It also shows why only one definite winding pitch gives the correct result, whereas a greater or less ratio gives a field in the wrong direction.

The correct combination in Fig. 6 (*b*) shows the rotor flux slightly lower than the stator flux, whereas if there were no leakage the currents and corresponding fluxes would be equal. but actually, the primary is a little higher due to the leakage. The difference between these two fluxes acts as a commutating field; but, on the other hand, the higher the leakage, the higher will be the commutating flux needed to overcome the leakage.



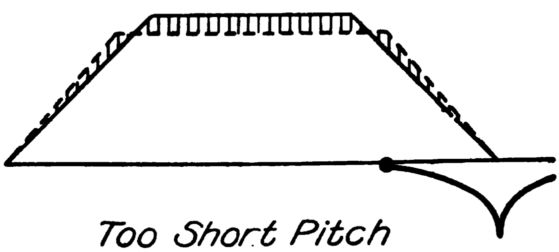
Full Pitch

Fig. 6a



Correct Pitch

Fig. 6b



Too Short Pitch

Fig. 6c

If, however, the armature is short-circuited through a reactive coil the resulting flux is increased without introducing leakage in the armature. Since the field of the motor is a reactive coil itself that must be excited, a convenient way of introducing reactance into the motor armature is to use the motor field or a part thereof for this purpose. That it is beneficial for the commutation of a repulsion motor to introduce the field in the armature instead of the stator circuit was experimentally demonstrated long ago by E. W. Rice, Jr. The reason for the improvement as explained above, is that the reactance of the field changes the ratio between stator and rotor ampere-turns so as substantially to offset the wrong distribution of currents with the full-pitched winding. The fact of the reactive coil

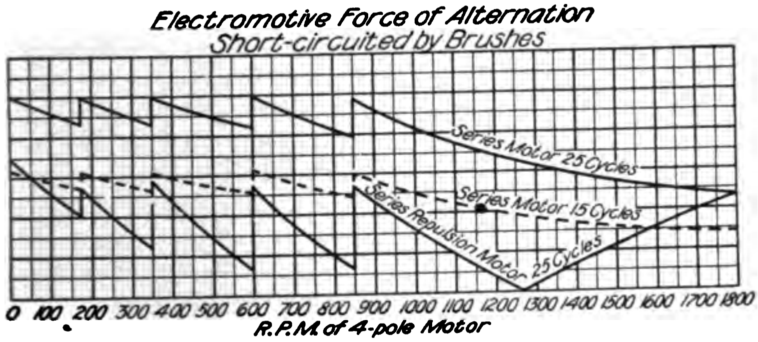


Fig. 7

being the field winding is in this respect immaterial, and it has been proved that the field of a similar machine introduced in the same place gives the same result.

The above discussion demonstrates how the two fundamental conditions for good commutation can be fulfilled in a series repulsion motor at any speed without the aid of commutating poles. Instead of creating a commutating flux artificially in a place where the commutated conductors happen to be, the conductors are located in a place where the correct flux will naturally exist. By controlling the value as well as the phase of the different fluxes as described, perfect commutation can be obtained at any speed.

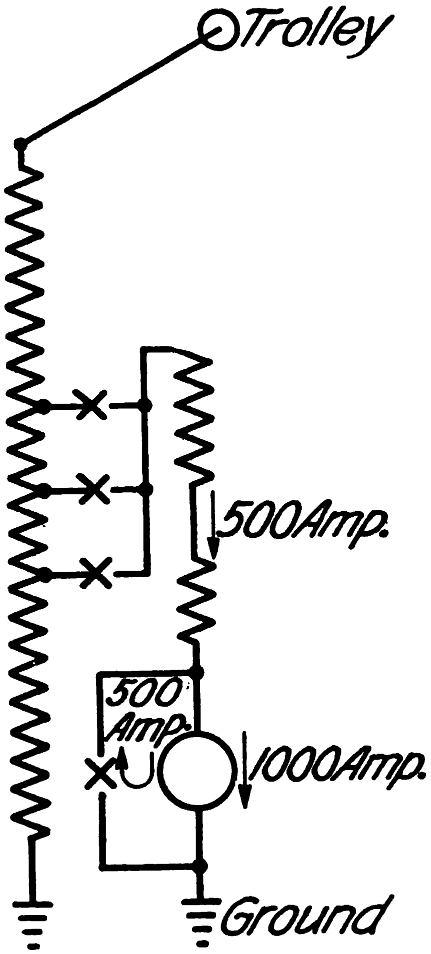
Fig. 7 gives a comparative diagram of the alternating voltages in the short-circuited coils of a series repulsion motor for 25 cycles and for the same motor when used as a series motor for 15 and 25 cycles. The improvement introduced by the fractional-pitch armature winding is a separate matter and is of the same character as the change from an ordinary direct-current machine to a commutating-pole machine.

Starting

The starting of a single-phase motor is materially handicapped by the fact that the alternating nature of the main field sets up currents in the armature coils which are short-circuited by the brushes. This same difficulty is experienced in all known types of single-phase commutator motors. Although the principle involved is the same in the motor under consideration, the practical result gained by the arrangement employed is a starting torque twice as high as would be possible in a corresponding series motor for the same commutation and the same supply of current.

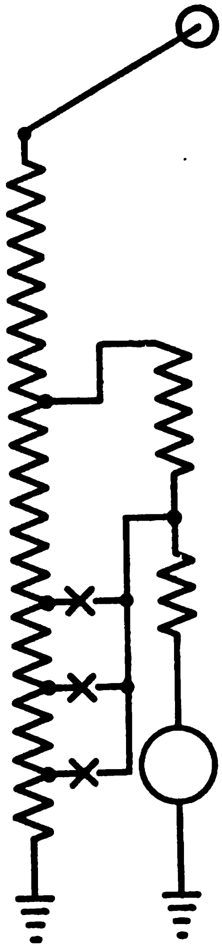
This double starting torque is obtained by winding the stator with twice as many turns as the armature. The motor starts as a repulsion motor with the armature short-circuited as shown in Fig. 8. The current as it enters the stator has only half the strength of that in the rotor, owing to the ratio of stator to rotor turns. The short-circuiting switch of the rotor carries only half as much current as the rotor itself, because the current in the short-circuited connection is only the difference between the stator and the rotor current. The inducing winding, the field, and the armature are connected permanently in series; but with the connections shown, the field is in series with the stator circuit at starting and with the rotor circuit when running. In starting, the rotor carries twice as much current as when running, in order to give the same field strength—in this manner doubling the starting torque. The sparking at starting is quite insignificant up to a certain value of the voltage short-circuited by a brush; but beyond this point the commutation rapidly becomes bad. This critical value is about the same as that which gives a reasonably good commutation in running. For a pure compensated series motor, therefore, the same remedy must be looked for in running as in starting conditions, and the natural solution is to design the motor for a low voltage or to use resistance leads.

In ordinary series motor equipments, the difficulty arises that a higher starting torque is usually required than the full-load running torque, and if the short-circuited voltage is permissible in running, it will get too high at starting. A starting torque of twice full load (one-hour rating) torque is, however, usually more than enough, and therefore the short-circuited voltages can



Starting

Fig. 8



Running

Fig. 9

be kept below the critical point, while the torque is increased above normal. It is, however, not only the critical value of the voltage, but also the time that such a voltage is maintained that determines what is permissible. In this respect any repulsion motor has a great advantage, because the sparking disappears altogether as soon as the armature has reached an appreciable speed. Furthermore, a voltage could be allowed in starting with double torque which would not be permissible with normal running torque, on account of the short time-element of the starting condition.

The general principle which has been discussed for regulating the field in starting an alternating-current motor can be applied in different ways; it was first employed by Eichberg, who used a variable series transformer in the field circuit. Particular attention may, however, be called to the simplicity of the arrangement described here, where the same result is acccomplished through the inherent characteristics of the motor without the use of any additional apparatus. The same principle can be appplied to series motors by the use of a series transformer or some suitable controlling device, but it involves the disadvantage of doubling the current which is to be supplied to the motor through the control system, whereas when starting as a repulsion motor, increased torque is gained by a local current superimposed on the main current by induction.

Control. In regard to the practical application of the system, it may be mentioned that several four-motor equipments for alternating and direct current have been in operation for some time. The alternating-current control equipment has a total of seven contactors and a reversing switch. This gives four points on the controller which seems quite satisfactory for motor-car operation, though any number of steps can be added to take care of locomotive operating conditions.

The preferred method of control is the one shown in Figs. 8 and 9. In starting, the armature is short-circuited and the full secondary voltage of the transformer is impressed upon the inducing and exciting windings. The current flowing through the stator continues through the armature, but due to the ratio of turns of inducing winding and armature winding, an additional current of equal strength to the stator current flows through the local circuit of the armature and the short-circuited connection. In the running connection, part of the power is introduced in the stator and part in the rotor, and the field winding carries the same current as the armature; that is, twice the stator current, thus giving a relatively greater field strength than in the starting condition, just as would be produced by a series-multiple connection of the field winding.

Although the total potential impressed upon the stator and rotor is the same for starting and running, the result of changing the connection so as to transfer the energy input from the stator to the rotor has the effect of increasing the resulting voltage of the motor. This is due to the ratio of transformation between stator and rotor. In this manner a higher speed is obtained by impressing a higher resulting voltage, and the same change of connections makes the motor adapted for a higher speed by changing the ratio of series and repulsion motor action.

Power-factor. The only motor that has an inherent claim on unity power-factor is the direct-current motor. In every alternating-current motor a certain amount of wattless volt-amperes is consumed in magnetizing the field, and in leakage, so that the maximum torque is limited to a lower value than with the direct-current motor. An alternating-current motor with inherently good power-factor is one with high overload capacity, and this must be due to a comparatively small proportion of volt-amperes being consumed for magnetization. There are, however, artificial methods of bringing the power-factor of the alternating-current motor up to unity. For example, an induction motor can be shunted by a condenser, and a commutator motor can be arranged so as to generate a certain amount of volt-amperes in order to supply its own magnetization. Any arrangement for this purpose does not improve the torque characteristics of the motor, any more than a condenser improves the performance of the induction motor; it improves only the phase displacement of the supplied current. The effect on the system can be corrected equally well by other machines on the same system adjusted for leading current.

The alternating-current series motor has a higher power-factor than the three-phase induction motor with the same magnetic structure, because the series motor generates a certain amount of volt-amperes. The power-factor of a series alternating-current motor can be increased to unity by displacing the phase of the field current; for instance, by shunting the field with a non-inductive resistance. In fact, the higher power-factor is due to internal shunt currents, the core-loss as well as the short-circuit current in the brushes having the character of shunts on the field winding. Eliminating the core-loss as well as the short-circuit currents in the brushes would, therefore, evidently improve the motor itself, although it would lower the power-factor.

The following is a short statement of the functions of the different fluxes in a repulsion motor. The motor is understood to be designed, as described before, with a definite degree of fractional pitch and the brushes in the neutral position.

Power-factor of the repulsion motor with field winding in stator circuit. In a repulsion motor, the current passing through the inducing winding produces a corresponding current in the armature. By the rotation of the armature in the main field, an electromotive force is generated in the armature, which causes a magnetizing current which is superimposed upon the main current, and it is this magnetizing current that causes the voltage to be transformed back to the primary. In other words, the current is transformed from the stator to the rotor and the electromotive force generated in the rotor is transformed back to the stator. One flux is needed to transform current and another flux to transform the voltage. These two fluxes are out of phase. The voltage flux is generated in the armature by rotation and does not consume any volt-amperes from the line. The main flux as well as the current flux and the leakage flux consume volt-amperes.

Power-factor of the repulsion motor with field winding in armature circuit. The theory of this motor is the same as above, except that it takes more flux to transform the current because the armature circuit includes the impedance of the field. Why this increased flux is good for the commutation has been shown above. The same magnetizing current for the voltage flux as described above flows through the armature, and in this case through the field also. This magnetizing current displaces the phase of the main field, and consequently the electromotive force of the machine. The displacement tends to lower the power-factor and the result is the same as if the volt-amperes of the voltage flux had been supplied from the line. In other words, the motor has the same inherent power-factor as a single-phase induction motor.

A series repulsion motor as developed for railway service has only one-third to one-quarter repulsion motor action, this being the proportion that gives sparkless commutation from synchronous to double synchronous speed. The lowering of the power-factor due to magnetizing current is therefore very slight, and with the greater liberty in design that is gained in the series repulsion motor, the power-factor is practically the same as in a series motor.

The analysis of the phase displacement also indicates how the power-factor can be corrected by shifting back the phase of the field current. This can be done in the series repulsion motor as well as in the series motor by shunting the field by a resistance according to the suggestion of Mr. A. S. McAllister. It can also be done, as has been experimentally demonstrated, by a slight degree of separate excitation of the field derived from the main transformer or from the stator coils. However, any raising or lowering of the power-factor of phase displacement does not affect the tractive effort or heating of the motor; it only changes the voltage that has to be applied in order to overcome the inductive drop. As soon as any artificial method of raising the power-factor involves any complication, for instance, another set of brushes on the commutator, it will probably prove preferable to improve the constants of the system by using synchronous machines wherever power is used for other purposes.

Resistance leads. The use of resistance leads, which has been so much discussed, has been found to be unnecessary in motors of the type described. Certain motors which have been operated for a considerable time as series motors, and then rewound so as to embody the features described in this paper, have shown an increased life of brushes and commutator up to the standard of good direct-current practice. The improvement in commutation was so great that it was possible at the same time to increase the thickness of the brush and the output of the motor.

Selection of frequency. In regard to choice of frequency, the series repulsion motor again gives greater liberty. Whereas the starting torque can be doubled on either 15 or 25 cycles, it may be mentioned that a series motor which was almost inoperative at a certain load at 25 cycles, after rewinding, as described, was tested as a series repulsion motor, and found to give excellent commutation at 40 cycles, at the same load. It can therefore be said in general that 25 cycles is entirely satisfactory for all geared motor work; it is preferable in that the combination of motor and transformer weighs less at 25 than at 15 cycles.

A general discussion of the selection of frequency really falls outside the scope of this paper, as the motor referred to is equally well applicable to 15 or 25 cycles. It is, however, the impression of the author that the only argument that remains for 15 cycles is the direct-connected motor for high-speed passenger locomotives. It is, therefore, a question whether the policy of the railroads in regard to frequency should favor 15 cycles because of the requirements of the design of a particular type of locomotive with a limited use, when the freight work as well as the multiple-unit motor trains can be handled more economically at 25 cycles.

Economy of material. The motor described can be built in larger capacities than the series motor. The principal reason for this is the inherently good commutation and increased starting torque which make resistance leads unnecessary, thereby eliminating the heat generated by the resistance leads, and also gaining space in the slots, which can be used for copper. Furthermore, it is possible to increase the flux per pole without impairing the commutation.

The fractional pitch winding which is used primarily for the sake of commutation is also advantageous from the point of view of economy of material. The saving extends not only to the end-connections, as is the case with the fractional-pitch induction motors, but also to the stator winding, inasmuch as only the active armature conductors, or only about 80% of the total, need to be compensated for; whereas with the full-pitch armature, the entire winding must be compensated for. In neither case is it possible to utilize more than about 80% of the total pitch as effective pole arc, because of the space occupied by the field winding. This principle is applicable to any type of compensated machine of the Deri type for alternating or direct current, except when the commutating pole is used.

The fact that the number of poles in the series-repulsion motor can be selected without regard to the synchronous speed is an important consideration. The tractive effort of an alternating-current motor referred to the periphery of the armature is directly proportional to the number of poles employed, provided that the same flux per pole is used and the same current density in amperes per inch of circumference. The allowable flux per pole depends upon the type of winding and thickness of brush, but the same limitations exist for all known types of motors. The formula for tractive effort given below is deduced from the fundamental formulas for commutator machines, but it is of special interest because it brings all motors to the same basis and shows the advantage of liberty in selecting the number of poles.

The tractive effort in kilograms at armature periphery =

$$\text{amperes per cm.} \times \frac{\text{flux}}{\sqrt{2}} \times \text{number of poles} \times \frac{1}{9.8}$$

The only constant in this formula is the acceleration of gravity, 9.8, in the metric system.

Tractive effort in pounds at armature periphery =

$$\text{amperes per inch} \times \frac{\text{flux}}{\sqrt{2}} \times \text{poles} \times 0.089$$

This formula also indicates which method can be considered to obtain as high a starting torque as possible with a given number of poles. The starting torque depends only upon the flux per pole and the current-density. The permissible flux can be slightly increased by use of resistance leads. A considerably larger increase can, however, be obtained by raising the current density momentarily without changing the flux. This is the method that has been adopted in the motor described.

At first glance it may appear that this method would lead to an overheating of the winding. This, however, is not the case. In a motor of this type the I^2R losses are of about the same magnitude as the losses due to the field and the rotation. The total losses of the motor are therefore not increased by the square of the current, but more nearly in proportion to the current. Furthermore, when an increased starting torque and increased acceleration are obtained by increased current, the duration of the excessive current will be so much shorter, with the result that a train can be brought up to a certain speed with only slightly higher heating if this is done at a higher rate of acceleration and with the use of an increased current.

In summing up the preceding the particular advantage of the motor described may be claimed to be.

1. Good commutation at all speeds without the use of resistance leads.

2. Larger capacities possible than with the series motor.

3. High tractive effort possible, due to the liberty of selecting the number of poles.

4. Increased starting torque, possible because of the inherent ratio of winding turns, without supplying an increased current from the main transformer.

5. Simplicity of construction. The stator is the same as in the series motor, in fact easier to construct due to the greater liberty of placing the field-winding in slots. The armature is constructed according to standard direct-current practice with the conductors soldered into the commutator bars.

6. Equally well applicable to direct and alternating current

DISCUSSION ON "A SINGLE-PHASE RAILWAY MOTOR." NEW YORK, JANUARY 10, 1908.

L. B. Stillwell: The announcement of a new motor is always interesting. When its novel features are such as tend to material improvement of performance or reduction of cost, it is not only interesting but important. When to improvement of performance and reduction of cost is added the consideration that the new motor is of a type upon the success of which depends largely the solution of the most weighty problems that electrical engineers are called upon to solve, the publication of the results of the inventor's work is an event in the annals of engineering.

Mr. Alexanderson and his associates are to be congratulated upon the production of a single-phase alternating-current motor possessing apparently at least one feature of marked originality and of much practical value—the elimination of the idle resistance in the armature winding is an important step. I have not been able to ascertain from the paper how much this step costs in other directions. The author states frankly that the motor is a compromise, combining, as he believes, the good features of the series compensated motor with those of the repulsion motor. Whether the compromise is an advantageous one, whether the characteristics of the new motor, under the conditions imposed in practical service, are such as render it, on the whole, superior to its competitors, is the question at issue.

The question of superiority is to be determined by com parison, not of one but of a number of factors. The strong point of the new motor appears to be its ability to commutate at high speed without sparking; at the moment of starting, however, the sparking apparently may be serious. Further light should be thrown upon this point. It would be interesting also to know what the power-factor is, both at starting and at speed.

But more important than either of these is the ratio of output to weight, since in heavy railway traffic motors must be placed within certain defined limits of space; for other things being equal, the best motor is the one that, within such limits and within reasonable limits of temperature and commutation, is able to deliver the largest sustained output.

In the paper entitled, "On the Substitution of the Electric Motor for the Steam Locomotive", presented at the 214th meeting of the Institute by Mr. H. S. Putnam and myself, the question whether 25 cycles or a lower frequency; for example, 15 cycles, should be adopted for heavy railway work was asked, and the opinion was expressed that "a frequency of 15 cycles is preferable and should be adopted." The oral discussion was energetic, and in the written discussion with which it was closed Mr. Putnam and I incorporated the following statement of opinion and summary of the positions taken by a number of distinguished engineers who had participated in the discussion:

The oral discussion which followed the presentation of the paper was conclusive, beyond our expectation, as regards frequency. So far as the general practice of engineers who may adopt the single-phase alternating current is concerned, we regard the matter as practically settled by the facts and opinions brought out by the discussion. The designing engineers of both the Westinghouse and General Electric Companies testified emphatically to the great increase in power of motors which can be realized by reducing the frequency, and while several speakers questioned the wisdom of now adopting a standard, no one came forward to argue that the higher frequency is preferable.

Mr. Lamme, to whom, more than to any other man, we owe the single-phase motor, stated that at 15 cycles the output of a given motor is from 25% to 40% greater than at 25 cycles and that his company had verified this by actual test.

Mr Storer testified that: 'You can get at least 30% greater output from motors with 15 cycles than with 25 cycles'.

Mr. Slichter, the engineer of the General Electric Company, who has immediate charge of the work of designing single-phase motors, said: 'There seems to be a unanimous opinion that the output of the motor may be increased some 30% to 35% by a decrease in frequency from 25 to 15 cycles.'

Mr. Potter, chief engineer of the Railway Department of the General Electric Company, after pointing out some of the difficulties in the way of the adoption of 15 cycles, said: 'I do not think, however, that we can look for the ultimate development of the single-phase motor of 25 cycles'.

* * * *

The paper and the discussion have established the fact that the increase in cost of the power house equipment consequent upon the suggested reduction in frequency is far more than offset by the reduction in cost of electric equipment of rolling stock consequent upon the adoption of 15 cycles.

During the discussion of Mr. Sprague's paper presented on May 21, 1907, announcement was made of a new motor which it was claimed performed so well at 25 cycles that the argument in favor of 15 cycles for heavy railway work was materially weakened. The motor referred to was that which has been disclosed this evening by its inventor.

In Mr. Alexanderson's paper little is stated relatively to performance of the new motor at frequencies lower than 25 cycles per second beyond the statement in reference to its commutation that it, " is equally well applicable to 15 or 25 cycles ", and that " it can, therefore, be stated in general that 25 cycles is entirely satisfactory for all geared motor work; it is preferable in that the combination of motor and transformer weighs less at 25 than at 15 cycles." Regarding the statement that the commutation is equally good at 25 or 15 cycles, it is to be regretted that the author does not show in Fig. 7 the curve of the electromotive force of alternation short-circuited by brushes when the motor is operated at 15 cycles. It is obvious that commutation at 15 cycles will be improved, and there is no reason suggested why this improvement, expressed in percentage, should not be as great in the case of this motor as in that of the series compensated motor. In the second statement quoted, one of the principal advantages of the lower frequency is entirely ignored. The relative aggregate weight of motor and transformer is unquestionably important, particularly in multiple unit work; but much more important, at least in the field of heavy electric traction, is the power of the motor that can be placed in a given space on the truck. The factor of cost is also against the 25-cycle motor. From the facts given, I believe that this new motor will gain as much in ratio of output to weight at a given speed by reduction of frequency from 25 to 15 cycles, as will the series compensated motor.

It seems to be a fair generalization to say that alternating-current motors having speed characteristics resembling those of the direct-current series motor will gain approximately 30% in torque, and will also gain materially in sustained power by reducing the frequency from 25 to 15 cycles per second. I find nothing in Mr. Alexanderson's paper to indicate that this motor is an exception to the general rule. If I have not understood it I shall be most happy to be corrected, as no one can question the weight of the arguments against the adoption of a new standard frequency, and such adoption can be justified only by the existence of controlling considerations such as those to which I have referred.

B. G. Lamme: This paper describes a certain type of single-phase commutating motor, and comparison is made with the series compensated type, generally to the apparent disadvantage of the latter. It is intimated that this motor does what the series compensated motor cannot do. The theme of the paper appears to be that successful commutation of alternating currents has at last been obtained. Instead of accepting these conclusions, I am free to state that I do not see that this motor does, or can accomplish more than has already been accomplished successfully by a properly designed series compensating motor. Further, I claim that the series compensated type, as already built, is in certain features so far ahead of the type described in this paper, that it looks like exaggeration when a comparison is made in figures. In this paper, describing what is claimed to be a new and superior type of motor, no characteristic curves or data are given, and consequently no quantitative comparison can be made with other designs.

Let us first consider the starting conditions and characteristics. The general scheme of starting is based on the use of a relatively weak field at the beginning, the field induction being increased, for the same torque, after sufficient speed has been attained to make the commutating poles effective. Theoretically, assuming no saturation of the magnetic circuit, this increase in induction could be approximately 41 per cent, but practically it would be but 20 to 30 per cent., the material in the machine being worked economically. The object of this relatively weaker field at start is to lower the voltage in the coils short-circuited by the brushes. Referring to commutating motors in general, the author says:

> The sparking at start is quite insignificant, up to a certain value of the voltage short-circuited by the brush, but beyond this point the commutation rapidly becomes worse.

The author admits that it is necessary either to keep below this critical voltage or to use preventive leads. This is the parting of the ways. It is either necessary to limit the design of the motor to such proportions that the induction at start can be kept down to such a low value that the short-circuit voltage is below the critical point, or, to take a broader course, to use preventive devices and thus raise the critical point and increase the output and improve the performance. Apparently the author does not believe that preventive leads, or resistance leads as he calls them, permit sufficient increase in the short-circuit voltage to represent any great gain in the operation. I disagree with him here, and will give some figures which I think will bear out my point of view. I am going to compare this arrangement with the series compensated type by assuming both to be applied to a motor corresponding to the present New Haven locomotive motors, which have a normal rating of 250 h.p. at 220 rev. per min. at 25 cycles.

This size of motor is selected for comparison principally because I have more data of various combinations of windings of armature and field than on any other large motor. In bringing through the first New Haven motors numerous arrangements were tested, such as fields with under- and over-compensation, commutating poles, etc., and armatures wound with and also without preventive leads. The combination giving the best all-round results is that used on the New Haven equipments.

These New Haven motors are worked at the time of starting at a high induction per pole, and in consequence at a high short-circuit voltage. Therefore, as this is a practical case it is fair to use it in making the comparison. But before making the direct comparison I shall digress slightly to take up the subject of currents flowing in the armature windings of single-phase commutator motors. Two currents should be considered: first, the working current which is fed into the brush and which passes into the commutator bars, through the connections, or leads, into the main armature winding; and secondly, a local or short-circuit current which passes from the short-circuited coil out through the lead or connection to one commutator bar, then through the brush to the adjacent bar and back through the lead to the coil. This local current is dependent upon the voltage generated in the short-circuited coil and upon the impedance in the closed circuit. If this local current could be limited to values approximately the same as the working current in the coils, then it could be taken care of very readily by the ordinary resistance of the brush, brush contact, etc.; but unfortunately a short-circuit voltage low enough to give this condition would give absurd proportions in the motor. In order to obtain a reasonable capacity from these single-phase motors, it is necessary to work at an induction giving a short-circuit voltage so high that this local current would usually be many times greater than the normal working current in the coils. It is for the purpose of reducing this short-circuit current to a more moderate value that preventive leads are added. It has been assumed that the addition of these leads means an increase in loss. However, as the purpose of the leads is actually to reduce the excessive local current, the result is a very considerable decrease in loss by the use of these leads. The following figures will indicate wherein these leads are beneficial.

Taking up again the comparison which I proposed to make, let us consider that, with either scheme of winding, the motor starts under double normal full load or one-hour torque. This condition occurs very frequently in the operation of the New Haven equipments, and is even very considerably exceeded at times. Under this condition of double torque, the motor with the series compensated winding has an induction of approximately 1.25 times normal and a working current in the armature and field of approximately 1.6 times normal or one-hour current. The preventive leads are so proportioned that the local or short-circuit current at this overload torque is, roughly, about 1.25 times the normal working current in the armature conductors. Next, applying the scheme described in Mr. Alexanderson's paper in order to get twice full-load torque, the field would have normal full-load induction, and the armature would have double normal current, compared with a field of 1.25 and an armature current of 1.6 in the compensated series motor with preventive leads. This double current in the armature with normal field strength would not look so bad if it were possible actually to operate satisfactorily under this condition without preventive leads. But with the high normal induction per pole on the New Haven motors, the tests show that it is utterly impracticable to start with normal induction in the field without preventive leads in the armature, for the short-circuit or local current is excessive and causes vicious and destructive sparking. Our data indicate that, without preventive leads, and using brushes of medium low resistance, such as are used in ordinary generators and motors, this New Haven motor will give a short-circuit of about seven times normal working current in the coils with normal full-load induction in the field. This condition is prohibitive and is far beyond the critical point mentioned before. Even reducing this induction to 70 per cent. of its normal value, the short-circuit current is still about five times normal current, which I consider to be too high. However, let us assume this value. The field strength at double torque would, therefore, become 0.7 instead of normal, and the armature current for the double torque would have to be increased to 2.86 times normal instead of double. The current with this arrangement would then be as follows:

Short-circuit approximately 5 times normal.
Working current 2.86 times normal.

These should be compared with the compensated series arrangement in which these values are:

Short-circuit 1.25 times normal.
Working current 1.6 times normal.

The total current required by the brushes and commutator in the compensated series motor would therefore be approximately one-third that required if the scheme described in this paper were used. Let us carry this analysis a little further. Assuming that we could start satisfactorily with the 0.7 normal induction indicated above, then when speed is attained a 40 per cent. stronger field could only be obtained provided there were no saturation in the magnetic circuit. But taking saturation into account, the increased induction would hardly be 30%. It is evident, therefore, that in order to accommodate the starting conditions, the normal induction must be sacrificed somewhat; and with the highest permissible field at start the normal induction would be considerably lower than if preventive leads were used. Another interesting point to be noted in these figures is the comparison of relative inductions at start with the two arrangements. It may be seen that the motor with preventive leads shows 1.25 times normal induction, while the method proposed in this paper shows 0.7 normal. The gain in induction by the use of preventive leads in this case is approximately 75%, and even with this increase in induction I am confident that this motor would make the better showing as regards sparking and burning at the commutator and brushes during starting, due to the greatly reduced local currents. The above figures also indicate clearly the disadvantage of trying to improve this condition by the use of high-resistance brushes. Necessarily the life of such brushes would as indicated be considerably shortened by the excessive currents.

This method of considering the currents flowing in the armature shows very clearly why 15 cycles is more advantageous than 25 cycles in the alternating-current commutating motor. As the short-circuit voltage is a direct function of the frequency, as well as of the induction, it is evident that with the same limiting short-circuit voltage, the induction could be increased in the ratio of 25 to 15, or 66%. It is evident, therefore, that the limit of induction at start is thus raised enormously. In practice, however, unless the motor is worked at extremely low saturation, the full gain of 66% can not be obtained either at start or at speed; for in order to obtain the greatest economy in weight and dimensions it would be natural to work the material at as high saturation as permissible, and in practice there would be only about 30% gain. As we could work 66% higher with the same short-circuit voltage, this increase of only 30% means that the short-circuit voltage is thus less than 80% that of the 25-cycle motor of corresponding design. There is thus about 30% greater output due to the higher induction, and at the same time this is obtained with a lower short-circuit voltage and therefore with more favorable starting conditions.

I have expanded on this starting condition, for experience with large motors shows that it is a most difficult one to meet in locomotive work. Also, tests indicate that the local or short-circuit current is a maximum at start, being close to the theoretical value, but falls off rapidly as the machine speeds up.

Mr. Alexanderson intimates that even if the losses are excessive in the armature winding at start, yet the quick starting and acceleration will greatly reduce the danger from this source. This may be true of small equipments where light torques are required, and quick acceleration always possible; for heavy work, however, there are many occasions where it is necessary to start very slowly and run slowly for a considerable time. I shall cite some of the tests made with the locomotive equipped with two 500-h.p. motors and exhibited at Atlantic City at the Street Railway Convention last October. This machine was given some very severe tests last summer at East Pittsburg, in the presence of prominent railroad engineers. In some of these tests the locomotive was operated for five minutes at speeds of from two to three miles per hour, and this while exerting more than double torque. This represents less than one-tenth the normal or rated speed of the motor. The motor was also held at standstill for considerable periods, developing excessive torques in attempting to start trains with the brakes set. Under this condition a motor without preventive leads would, unquestionably, have been ruined. This condition of the motors at standstill, with a heavy current flowing, is particularly liable to be met with in freight service, especially if two or more locomotives are working independently with a very heavy train. It will be impracticable to start all the locomotives at the same instant, as they may be in different parts of the train; consequently, one locomotive may develop a high tractive effort at standstill for some little time before the other locomotives are thrown in. To meet such conditions in practice requires a motor that can be held at standstill for more than an instant when developing heavy torque. It has been claimed by some engineers that under this condition the preventive leads, or resistance leads as they are called, must necessarily burn out, because they have a large loss in them at this time. It is under this very condition that the motor with the preventive leads shows to great advantage over the one with excessive short-circuit currents, and without such leads. As mentioned above, this explains why the latter type of motor is liable to be injured during a failure to start; it will not do simply to say that on account of rapid start and quick acceleration the motor will not be injured. In freight service, the opposite condition of starting must be handled with certainty.

It may be said that Mr. Alexanderson's motor is a true commutating-pole type of machine, but instead of using a separate pole placed in the interpolar gap the two edges of the main pole are used as an interpole. This may be illustrated by the following diagrams.

In Fig. 1 is shown the ordinary arrangement of winding with an interpole, the winding being the full pitch. In Fig. 2 the interpole is shown at one side. In Fig. 3 the pitch of the coils is shortened and the interpole is widened a corresponding amount so that this pole still covers the armature coils. The pitch is narrowed until the two sides of the coil lie under the two edges of the main pole. The width of the interpole is, therefore, such that it would overlap the main poles, if superimposed. It is evident that the centre of this interpole is useless and could be cut away as shown in Fig. 4. As this pole overlaps the main poles in position, it is evident that the edges of the main poles themselves could be used as interpoles if the winding surrounding the interpoles is properly placed in the main poles so as to surround these two edges. This is just what the compensating winding does. The effect, therefore, is the same as if interpoles were used, for part of the main pole is converted into an interpole, as shown in Fig. 5. However, since it is evident that part of the main pole is converted into an interpole, it is also evident that part of

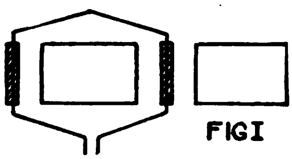


FIG I

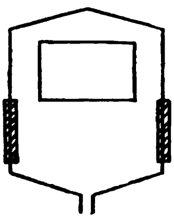


FIG II

the main pole, used as an interpole, represents that much loss in the effectiveness of the main pole. In other words, the armature coil does not surround all the induction from the main poles, but only part of it, and in consequence of this reduced effective induction the counter electromotive force of the machine is reduced. Another way of putting it is that the effect is the same as reducing the number of armature turns. In order to bring the effective induction of the main poles up to the required value, more exciting ampere-turns are required. This means that the power-factor of the machine is lowered somewhat by this arrangement.

In these single-phase motors the object is to get the polar area as large as possible, so that with a given total induction per pole the excitation, or exciting ampere-turns, may be as low as possible. This insures a high power-factor. In Mr. Alexanderson's motor this condition seems to be departed from considerably. In the Siemens-Schuckert motor the commutating pole is placed in the interpolar gap and excited in shunt with the main circuit. This arrangement gives the benefit of the full pitch winding, and the effective polar area is relatively high; possibly 15% higher than in the motor described in this paper. In the motor designed by me the polar area is relatively a little less than in the Siemens-Schuckert, possibly from 3 to 5 per cent.

In reference to frequency, the author says broadly, but without argument, that there is little or no field for the 15-cycle motor. The only basis for this statement is apparently that good commutation is now possible at 25 cycles. In the discussion of the paper by Messrs. Stillwell and Putnam last January, it was not

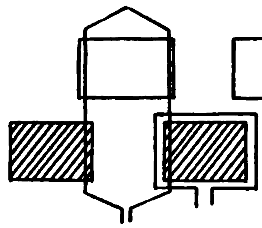


FIG III

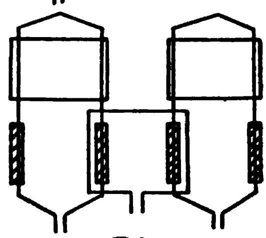


FIG IV

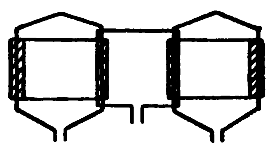


FIG V

the question of commutation which was advanced as the reason for the adoption of 15 cycles, for it was stated plainly that 15-cycle motors could be made to commutate well. The greatly increased ratio of output to dimensions was given as the principal reason for the adoption of the lower frequency. I see absolutely nothing in this paper to change that conclusion. The motor described this evening, if properly designed, should show just as much improvement at 15 cycles as the series compensated motor; for, as explained before, the use of a lower frequency will allow about 30 per cent. increased induction. In fact, this motor, being worked at a relatively lower induction at start than the series compensated type, and therefore at less saturation, should show a relatively greater per cent. gain at 15 cycles as regards starting, and when at speed should also show practically the same per cent. gain as the compensated type. Of course this is not on the basis of simply taking a given motor built for 25 cycles and operating it on 15 cycles, which will show a small gain. But the excitation, or exciting ampere-turns, must be increased, and this can be done at the lower frequency without reducing the power-factor; for the inductive volts across the field winding are a function of the frequency as well as of the induction, and thus any reduction in frequency will permit an increase in the induction of the motor. A 30 per cent. increase in the induction of such a motor means a 30 per cent: increase in the counter electromotive force of the armature; and with the same current flowing, the output and the torque are increased at least in proportion to the field strength. It is in this feature of increased induction that the principal gain with lower frequency is to be found. This increased induction is obtained with less short-circuiting in the armature and also with less exciting voltage in proportion to the counter electromotive force, and consequently with higher power-factor. If it were possible to design a 25-cycle motor of large capacity and moderate speed, so that it could be worked at high saturation, then there would not be so much gain in weight and cost by the use of lower frequency, for extra material would have to be added to the magnetic circuit when the induction is increased. But on the larger sizes of 25-cycle motors the iron cannot be worked to high saturations because it is not permissible to put in excitations sufficient to saturate the motor. In fact, it is in general difficult, in such motors, to get in enough excitation for the air-gap alone, unless the field volts are made undesirably high, thus lowering the power-factor. In consequence, on large, moderate-speed, single-phase, 25-cycle motors there is a strong temptation unduly to reduce the air-gap in order to keep down the excitation and thus decrease the size of the motor. In the 15-cycle motor, on the contrary, a considerably larger air-gap can be used than on 25 cycles, due to the fact that there is much more margin for excitation without reducing the power-factor below desirable limits.

If the commutation at speed were the only limit in the 25-sycle motor, then it would be correct to say that with this limit raised sufficiently there would be no necessity for the lower frequency, but as the present limits in design of large 25-cycle motors lie in the excitation permissible with good power-factor, and in the short-circuit voltage at start, it does not seem to me that the problem is solved by simply applying a different method of obtaining commutation when running. The real limits which affect capacity still remain, and I do not see wherein the motor described this evening changes the broad problem in any way. I believe that if Mr. Alexanderson continues his investigations, especially with large motors for heavy railway service, he will be forced to the same conclusions.

W. B. Potter: The single-phase motor described by Mr. Alexanderson possesses a number of novel features, but the essence of the improvement is the better inherent commutation. Because of better inherent commutation it is possible to modify the other features affecting the performance of the motors which have heretofore been subordinate to commutation, with the natural result of greater reliability, decreased maintenance, and greater capacity for a given amount of active material.

It is very desirable that the motor equipment of a motor car should be able to develop sufficient torque to slip the driving wheels; for an electric locomotive this is particularly desirable.

Mr. Lamme questions whether a single-phase series repulsion motor will have an output equal to that of a series motor. I call his attention to a recent test of a series repulsion motor having the same armature dimensions and number of poles as the series motor on the New Haven locomotives to which Mr. Lamme refers. I understand that this New Haven motor has a limiting tractive effort of about 5000 lb. The series repulsion motor on the basis of the same diameter of driving wheels gives a tractive effort in starting of 7500 lb. and good commutation up to 75 miles per hour.

An electric locomotive is, figuratively, a draft horse, and its value as such is proportional to the weight on the drivers. In whatever degree the draw-bar pull is limited by the motors, the value of the locomotive, as a tractive machine, is decreased to the same extent. In the handling of any service, sufficient draw-bar pull to start a train is absolutely essential, the horse-power rating for maintaining the schedule being subordinate and depending upon the degree of continuous service. As affecting reliability, the motors are liable to injury from overload unless the load is limited by the slipping of the wheels rather than by the commutation or current capacity of the motors.

With any probable design of motor car or locomotive, the geared series repulsion motor will be able to slip the wheels even if geared for maximum speeds as high as 75 miles per hour. In the light of present knowledge, the problem is somewhat more difficult with the gearless series repulsion motor. With respect to the torque of the gearless motor, the state of the art to-day is not unlike that associated with the geared motor about two years ago.

In the many problems that arise in electric traction, a liberal discount may well be allowed for improvement. For those concerned in development and design, progress in new and untried fields is a privilege and duty, but for those interested only in the earning capacity a conservative attitude will usually best insure economic results. I would not counsel undue caution, but even with the radical improvements which have been made in the single-phase motor, it does not yet follow that single-phase traction is properly applicable to all conditions. A knowledge of the art of compromise constitutes the basis of most of our work, but the equations to be considered are lacking in their most essential feature if they do not contain the dollar sign as applied to each particular problem.

O. S. Lyford, Jr.: Many of us thought the repulsion motor dead, and we rather hoped it would stay dead, not that we had anything particular against that type of motor, but because we are beginning to get acquainted with the series single-phase motor which is serving us well. I should like to see one type perfected rather than two or more. If, however, the development of the motor which Mr. Alexanderson has described means a reduction in the cost of single-phase equipment, it will be welcome, as the price of such equipment is now certainly close to the prohibitive limit.

W. I. Slichter: The motor described has so many new features in its make-up that it is rather perplexing to grasp the principle of its action as a whole. It may be of interest to discuss these features separately and from a slightly different point of view from that taken by Mr. Alexanderson. In explaining the motor it is necessary to consider separately, the conditions of starting and running, as certain features are introduced simply to assist in starting, and other features are employed only to function when running.

Starting. In all single-phase commutator motors there is a definite value of the flux per pole above which it is inadvisable to operate, since the electromotive force of transformation in the short-circuited coil undergoing commutation becomes so great as to give unsatisfactory commutation. This limitation is particularly strict at starting, when the armature is at rest or moving very slowly. As the motor speeds up it would be possible to use a higher flux value; first, because each coil is under the brush for a shorter period; secondly, because there are various means of counteracting the electromotive force of transformation by devices dependent upon the speed of the armature.

But in all series type motors the natural characteristics involve a decrease in current with increasing speed, and hence a decrease in flux. If, therefore, a motor is designed with a proper value of flux at starting, it will have too little flux at running; if with a proper value at running conditions, it will have too great a flux and bad commutation at starting. This limitation does not prevail in direct-current motors, since any value of flux may be used without harmful effect.

In the motor under discussion the compensating or inducing winding and its inductive relation to the armature turns are made to act as a series transformer. By winding the compensating winding with twice the number of turns as are on the armature, there will be twice as much current in the rotor as in the stator when the rotor is short-circuited, and the same current in both members when the rotor is open-circuited. This gives an approximation of the ideal conditions in a single-phase commutator motor—that of operating at all speeds with the strongest field compatible with good commutation.

Running. Under running conditions we find in this motor three very important new features contributing to good operation.

1. The proper field strength at all speeds, as just mentioned.
2. By means of a fractional pitch in the armature (Fig. 1), the coil undergoing commutation is placed in a position under the pole piece, where it is very strongly influenced by any magnetomotive forces in the compensating winding, so that the latter winding is able to act as a real commutating pole as well as a compensating winding.
3. The compensating winding is made to carry two components of current—a series current and a shunt, or repulsion motor current. It may be likened to a commutating pole having two coils, one a series coil serving very effectively, due to

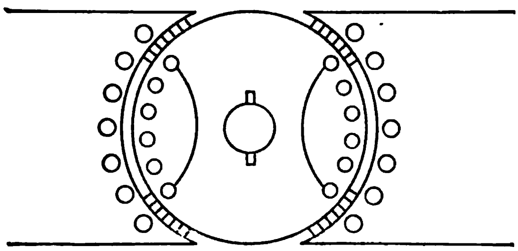


FIG. 1.

the favorable position of the coil undergoing commutation (brought about by the fractional pitch), to produce the good effects on commutation that a commutating pole does in a direct-current motor; in other words, to correct for the harmful electromotive forces of self-induction and armature reaction. This is accomplished by making the compensating winding stronger than the armature winding, thus the excess of compensating winding magnetomotive force sets up a local flux at the corners or tips of the poles which becomes a commutating pole.

The shunt coil, shunt component of current or repulsion motor current, corrects or reduces the electromotive force due to transformer action in the coil undergoing commutation by a happy combination of phase relations, as shown by the following vector diagram, (Fig. 2).

E_0 is the line or terminal voltage of the motor.

I_0 is the series-load current of the motor lagging behind E_0 a small amount, as in normal running conditions.

ϕ_m and ϕ_c show the time-phase-position of the two fluxes, motor and compensating, produced by I_0. These have different space-positions.

e shows the harmful electromagnetic force of transformation in the short-circuited coil, 90° behind ϕ_m, because ϕ_m produces it by induction.

A portion of E_0 is now impressed across the compensa ing winding in shunt, producing a flux ϕ_1 90° behind E_0. But the compensating winding is wound opposed, or 180°, to the armatu-e winding which throws this flux down to ϕ_2.

The armature coil moving in this flux has generated in it by rotation an electromotive force, e_2, in phase with ϕ_2 which is approximately opposed to e, combines with e to make the resultant e_3, which is of very small magnitude and of such phase

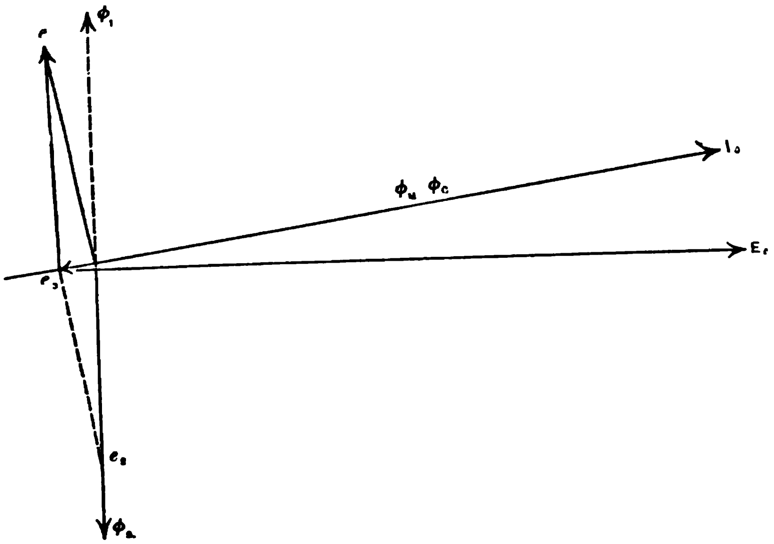


Fig. 2

as to be subject to the corrective influence of the flux ϕ_c of the ordinary compensating winding.

The final result is that the commutation troubles of the single-phase commutator motor are corrected in the logical way of removing the cause instead of the half-hearted way of reducing the effect, as is done with high-resistance leads.

A certain number of wattless volt-amperes are consumed in producing this effect, but a considerable amount of energy is saved and removed from a place which is particularly sensitive, the commutator, and a very large saving is effected in maintenance.

One of the immediate results of the development of this motor is the fact that it makes the need of 15 cycles for single-phase railway work a great deal less important than with either the plain repulsion motor or the plain series motor. As brought out in the discussion of Messrs. Stillwell and Putnam's paper, the greatly increased cost of generators and transformers at 15 cycles is a considerable handicap to that frequency, and with the former types of motors a 15-cycle system showed a lesser cost only in very heavy work where a large number of heavy motors were required. With the new motor, a considerable portion of the field of the 15-cycle motor has been conquered, and although the new motor is slightly better at 15 cycles than at 25 cycles, it will probably be found that there are very few cases where any 15-cycle motor and its transformer will weigh or cost as little as this type of motor and transformer at 25 cycles.

In the control of this type of motor it will be noted that the sequence of steps is very simple, and that each contactor handles only one half the maximum current used, thus the switches or contactors will be reduced in size and number and the equipment made considerably lighter. Also, due to the fact that the terminal voltage of the motor is higher, there is a saving in the weight of the car compensator or autotransformer.

Mr. Alexanderson's scheme of using a fractional pitch winding on the armature overcomes the principal objection that was found in the use of the repulsion motor in this country. The objection being that the simple repulsion motor does not operate satisfactorily on direct current, due to the fact that with a full-pitch winding commutation would take place in a field unfavorable to commutation, since the neutral space is necessarily restricted in this type of motor.

To be successful in this country, any single-phase motor must be capable of operating over the existing direct-current systems. This gave the series compensated motor an advantage over the repulsion motor for interurban work, but with the motor under discussion to-night, this difficulty is removed. We have developed a repulsion motor which operates perfectly satisfactorily on direct current.

S. M. Kintner: I am disappointed because Mr. Alexanderson has not told us more about the behavior of the motors in actual service. The theory is nicely worked out, but I for one would be better satisfied with less theory and more matter of a quantitative nature. For instance:

1. What is its power-factor?
2. How does it compare in weight with standard direct-current motors of equal torque?
3. How does its commutator wear in service requiring frequent acceleration with large torque and corresponding heavy currents?
4. What character of brush is used, and what life in car-miles is obtained?
5. How long can it stand locked with 150% full-load torque?
6. How does it stand sustained overload torques of 150 per

cent.—200 per cent. of the hour ratings, for periods of 3 or 4 minutes, when operating at normal speed and also at very low speeds?

The above conditions are the critical ones in the operation of single-phase motors, and it is upon their ability to stand such tests and service that their value should be based. Mr. Alexanderson's commutating-pole motor will probably give good commutation when running, but so will any well-designed series compensated motor with preventive leads. It is not the running but the starting condition that is the troublesome one; it is then that motors with preventive leads show their greatest superiority over those without them. The proposed method of obtaining improved running commutation is of questionable value when it is obtained, as Mr. Lamme has pointed out, at the sacrifice of starting torque and power-factor or by increase of motor weight.

The power-factors of a certain line of series compensated motor, with which I am familiar have the following values:

Twenty-five cycle motors, varying in size from 75 to 250 h.p. at their hour ratings, power-factor = 85% to 90%.

Fifteen cycle motors, varying from 75 to 500 h.p. power-factor = 88% to 94%. Some of these 15-cycle motors are simply 25-cycle motors adapted to the 15-cycle service. All of these values are taken from motors having reasonable speeds and good commercial air-gaps.

Data on weights on those same motors show that in comparison with the standard line of direct-current motors on a basis of percentage weights for equal torques, the 25-cycle motors weigh 33 per cent. more, while the 15-cycle motors weigh 10 per cent. more. The weights in all these are total motor-weights, including gears and gear-cases.

In checking over these values a noticeable matter was the limitations that the 25-cycle motors were reaching; for the larger size motors the percentage weights were increasing quite rapidly. This was not noticeable within the limits checked on the 15-cycle motors. This limit in the 25-cycle motor is caused largely by the increase in iron necessary to keep down the inductive element and consequently secure a reasonable power-factor.

Recent calculations show that in a given space it is possible to get a 500-h.p. motor on 15 cycles, but the best that could be designed for equally good performance on 25 cycles was 360 h.p. From this it is evident that 39 per cent. greater output is possible in the same space with 15 cycles. This indicates very clearly the need of 15 cycles for the heavier class of service.

The motor described by Mr. Alexanderson is limited in precisely the same manner as the series compensated type, and at smaller ratings. It will also be benefited, so far as output for a given weight is concerned, by the use of 15 cycles.

In dismissing the question of 15 cycles, Mr. Alexanderson admits that for large gearless motors for high-speed service there is an exception. Why except this class of service? Is commutator speed the reason?

A comparison of two 4-motor equipments made up of 75-h.p. motors at 25 cycles and the same motors adapted for 15 cycles giving 95 h.p., shows very clearly the gain in tractive effort and horse power possible with the 15-cycle motors. The total electrical apparatus per car was but 5 per cent. heavier with the 15 cycles, but the gain in horse power was 26 per cent. On a basis of total car-weights, the differences were 1.6 per cent increase in weight on 15 cycles and a gain of 26 per cent. in horse power.

The commutator wear in service requiring frequent and rapid acceleration is a serious one. A commutator that will not take a gloss, will rapidly consume brushes and soon go to pieces. If the currents are heavy at starting, and the starting frequent, the commutator is apt to have copper drawn from bar to bar and thus short-circuit certain coils. To show the limitations of a motor of this character, a test should be conducted as follows: the motor should be mounted on a shaft driving large fly-wheels, the inertia of which corresponds to that of heavy cars accelerating from rest. The control should be arranged so that as the wheels are accelerated the proper sequence of switch operations and voltages is applied to the motor. When a predetermined speed is reached, the power is cut off and the motor allowed to coast for a fixed time, when brakes are applied and the wheels brought to rest. This same cycle is repeated automatically by a motor-driven control, the single-phase driving motor being thus subjected to a service more severe than any it is apt to meet in operation on a car. This is an excellent test of the motor's ability to stand heavy currents while at rest, also while accelerating slowly, as it is connected rigidly to the shaft and gets the full force of the first rush of current.

This test should be continued for a week or more. The current used should be much in excess of the motor's ratings, and forced air will be necessary to keep down the temperatures to safe limits. The test is not one of temperature, but one of commutation under abnormal service conditions.

This test is also quite effective in determining carbon-brush characteristics. Within the last few days I have compiled some data gathered from a road operating approximately 100 motors of this kind, each of 100-h.p. capacity. This road reports the car-miles per brush as follows:

October	November	December	Average
14,600	15,550	15,450	15,200

The motors from which these data were taken are in very hard service, the cars averaging over 200 miles per day. On one run the car is compelled to make 583 miles per day. During October one car ran 10,740 miles; during November, 9,400 miles. Another road using similar motors reports approximately 13,000 car-miles per brush as the average for the last two months.

These motors have all been in operation over a year and have brushes of a medium grade, such as are used on direct-current motors and generators.

The ability of motors with preventive leads to stand excessive overload torques when locked for periods of 10 or 15 seconds has been demonstrated repeatedly by testing them after being on cars or installed on locomotives. These tests have been made by applying power with the brakes locked, and at other times by attempting to pull trains upon which the brakes were not released. The requirements of overload are largely at starting; they are not so important when running. During the last year and a half I have followed closely the operation of about 600 of these motors; I do not recall a single case of trouble that could be traced to a preventive lead burning out.

While many may look upon preventive leads as a luxury, in my opinion they supply the most economical design possible with single-phase motors in the present state of the art. I believe that they will continue to be used until some one devises a motor that is not subject to the short-circuit action in starting, as well as in running. Mr. Alexanderson's motor does not fulfil this requirement, and I see no reason why it could not be improved by adding preventive leads.

Mr. Potter says that with the Alexanderson motor it is feasible with motors of the same dimensions to get 50 per cent. more tractive effort than that of the New Haven motors. So long as the torque of motors depends upon the number of conductors on the armature, the limits of which are determined by the size of commutator with reasonable bar-width; secondly, upon the induction per pole, which is admittedly lower than that in the New Haven motor; and, finally upon current—my opinion is that it cannot be done with reasonable currents for the possible size of commutator.

Chas. P. Steinmetz: It is true and has been well known since the early days of electrical engineering, that any direct-current motor can operate on alternating current if its magnetic field is laminated so as to be responsive without excessive loss to rapid alternations of magnetism. But there were two great objections to this motor, both well recognized in the art before any extensive work was done; these objections were impracticably low power-factor and hopelessly bad commutation. I remember reading as far back as 1889 in Mr. Gisbert Kapp's at that time classic booklet on alternating-current machinery, the proof that the single-phase alternating-current motor can never be of any practical use, because its power-factor must be too low for practical use. The first problem that had to be solved in getting an operative motor was to raise the power-factor to practical values. This was undertaken and solved about eighteen years ago by Rudolf Eickemeyer, who gave us the compensating winding, which is now used in all single-phase alternating-current motors. He recognized that to give a good power-factor, the single-phase commutator motor must have few field turns, many armature turns; that is, a weak field with a strong armature. To be able to use these proportions, the armature reaction and self-induction must be neutralized by a compensating winding; a coil surrounding the armature as closely as possible and energized either by the main current in series and in opposite direction to the armature current, or closed upon itself and energized by its secondary induced current. Eickemeyer gave us both types of operative alternating-current commutator motors, the conductively compensated, and the inductively compensated. Thirteen years elapsed before the electrical industry caught up with Mr. Eickemeyer's work, and the compensated series motor was applied to commercial service.

Independent thereof, and starting even earlier, an apparently entirely different type of motor was experimented upon and designed by Elihu Thomson. This was the so-called repulsion motor. On converging lines these two motors have continued throughout the intervening period, until now in Mr. Alexanderson's series repulsion motor they merge into one. Mr. Alexanderson's motor is not a compromise between the two types of motors, but a modification of the repulsion motor so as to give at all speeds the perfect commutation that the repulsion motor has only at synchronous speed; that is, perfect commutation at all speeds by producing the condition of synchronous commutation at any desired speed.

After Mr. Eickemeyer's work was concluded, and the compensated series motor had arrived, there remained the problem of commutation, which has been the great problem of the alternating-current railway motor during the last few years, although frequently it has been more or less hidden under statements regarding size, weight, etc. Looking into the design of the compensated series motor, it will be found that there is no other inherent reason why it should differ essentially in weight or size or capacity from the direct-current motor, if it were not for the severe limitations in the design imposed by the problem of making the commutation sufficiently good not to be self-destructive in too short a time. The problem of getting reasonably fair commutation means that the alternating-current motor has to be designed with eight or twelve poles, where the direct-current motor would have four or six poles. It means that the alternating-current motor has to be supplied with a very large commutator to receive current at 150 or 200 volts, while the direct-current motor commutates much smaller currents at 500 and 600 volts. It is as easy to insulate 600 volts alternating current as 600 volts direct current, and so nobody would choose such large low-pressure currents and bulky commutators if not forced to it by the problem of commutation. So weight and size must be sacrificed to get moderately reasonable commutation. Some advantage is gained by the introduction of high resistance or high inductance leads. It must be realized, however, that the high resistance or high inductance leads, suggest, in a measure, the old saying, " Out of the frying pan into the fire." Reducing the short-circuit current by interposing resistance or inductance results in a drop of potential across the resistance or inductance which appears at the edge of the brush when the brush leaves the commutator segment. So sparking can not be entirely stopped by this means. The logical way to improve commutation is to remove the cause of sparking, the short-circuit current under the brush.

Some years ago one of my assistants, Mr. Milch, investigated the short-circuit current under the brushes, and found that it could be eliminated by impressing a commutating field upon the motor at the commutation point, or in quadrature with the main field. By giving the compensating winding more ampere-turns than the armature, or by using a series commutating pole or an interpole arrangement that works successfully in the direct-current motor—the commutation of the single-phase alternating-current motor cannot be improved, because the alternating current has an intensity as well as a phase, and the magnetic flux of the inter-pole being in phase with the main flux and main current, is wrong in phase. A commutating flux is necessary; a flux that differs in phase from the main flux, and is approximately in quadrature therewith. The production of such a magnetic flux, or a true commutating flux varying with the speed in the proper manner and differing in phase from the main flux, is what makes this series repulsion motor commutate perfectly at all speeds.

Another valuable feature of Mr. Alexanderson's work is the investigation of the distribution of the magnetic field. It is not sufficient merely to have the two quadrature components of the magnetic field of proper intensity and proper phase; what is essential in commutation is not the total quadrature field, but the field at the point where the brushes stand. This fact made it necessary to investigate the local distribution of the magnetic field over the armature circumference. The result of this work, then, eliminated the question of commutation from the alternating-current single-phase motor at all speeds.

It is true that at standstill the short-circuit current is still there, and must always be there, except that it may be interchanged against voltage by inserting resistance or inductance. It must not be overlooked, however, that the harmful effect of the short-circuit current is a function of the product of the current and the time during which the current exists; in this respect a motor in which the short-circuit current practically disappears at extremely low speeds has the advantage over a motor in which the short-circuit current retains the same relative proportion to the main current throughout all the speeds up to the highest. I believe this feature is the explanation of the great difference between Mr. Lamme's theoretical conclusion and Mr. Alexanderson's practical experience on one and the same size of motor.

It appears to me, therefore, that the second and last serious problem of the alternating-current motor which still remained after Eickemeyers work, the problem of commutation, has finally been solved by the work recorded in the paper before us. The alternating-current single-phase motor is in practically as good a shape as the direct-current motor, and I may perhaps say that with this work the second period in the development of the alternating-current railway motor, the period of youth, is concluded.

W. S. Murray: It is better to eliminate the cause of, rather than remedy, a deleterious effect. Thus an arrangement which naturally produces a proper commutating flux without especially providing extra means for it (such as commutating poles) is certainly a most valuable point gained.

Again, the elimination of resistance leads on account of the elimination of the cause requiring them is a welcome characteristic. We are all aware of the advantages, in high powered electric locomotives, of gearless construction; we are likewise aware, in this form of construction, of the high ratio of weight on drivers to tractive effort developed with alternating-current motor construction. In consequence of this unfortunate relation, should the entire electric locomotive weight be on drivers, it is impossible to design the motor equipment of sufficient capacity to slip the wheels of the locomotive; and as the transformer action is a maximum at starting, unless the locomotive enigneer shuts off power promptly upon finding the locomotive incapable of moving its trailing load, the resistance leads will burn out.

Mr. Alexanderson gives the general superior characteristics of his motor over those of the repulsion type. Since the introduction of the series compensated motor, I had been under the impression that the repulsion type could hardly be considered a competitor, due to the bad operating characteristics above synchronous speed, as explained in Mr. Alexanderson's paper. This new type of series-repulsion (which by the way might have its name reversed and be called repulsion-series, as it has to start before it runs) combining the good characteristics of the repulsion type for starting and the good characteristics of the series type for running, brings about a worthy competitor and lifts the mark of alternating-current traction to a higher notch.

Alternating current no longer recognizes direct current as a competing agent in the transfer of power. Commercially, they are in limitation to each other in this respect from a unit point of view in the ratio of 1 to 10,000; and so even though low transmission losses by alternating-current transmission may compensate for increased costs of traction apparatus, with its attendant lower efficiencies and greater non-revenue weights, it is a welcome sight to observe the alternating-current motor designer, not satisfied with this, but setting up for his model of accomplishment a motor the equal in every respect to its direct-current confrére.

The feature of producing double torque at starting by short-circuiting the armature and without increasing the line current is a characteristic that lends itself in much value to traction necessities. Although the point is not brought out, I assume that this arrangement prescribes that the motor operates at half of what the speed would have been had the short-circuit not been applied to the armature. In this connection it would be interesting to know what change of relation takes place between time and the temperature of the motor when developing double torque, also how the power-factor of this motor compares with that of the series compensator type for starting and low-speed conditions.

It would be interesting, further, to know how the weight per axle horse power one-hour rating compares with direct-current motors of the same size, also what the ratio of hour to continuous capacity prevails in this class of motor.

E. F. Alexanderson: In answer to Mr. Stillwell's question whether the increased capacity in changing from 25 to 15 cycles applies in the same rate to the series repulsion as to the series motor, it can be said that if the heating of the motor is the limitation, it does not apply; if the starting torque is the limitation, it does apply. In the case of a motor that can slip its wheels, the heating is the limitation; in that case the 15- and 25-cycle motors have virtually the same output.

A direct-connected motor may be called upon to give higher torque than is practical to obtain on 25 cycles, and in this case the ratio holds.

I thoroughly appreciate Mr. Lamme's contention that resistance leads increase the torque of the series motor by allowing the increase of the flux which is one factor necessary to torque. The other factor is the current, and by changing the ratio of excitation the current can be increased more than the flux could be increased by the use of resistance leads. The motor gives double torque with normal flux, and double current and normal torque with 70% flux and 140% current. The cross-currents in the brush may seem excessive, but they do no harm.

On a 50-ton locomotive that has been in service for half a year, hauling trains of about 400 tons, the motor slips its wheels without damage to the commutator, although it has not the improved arrangement for starting referred to in this paper.

Mr. Lamme made particular reference to the New Haven motor with a rating of 250 h.p. at 220 rev. per min. for one hour. I am familiar with this motor, because I have designed a repulsion motor for the same purpose with the same outside dimensions. This motor has been tested and has an output of 280 h.p. continuously, and 350 h.p. for one hour at the speed indicated by Mr. Lamme. This increase from 250 to 350 h.p. at the hourly ratings of the two motors is fully as high as the increase claimed by changing from 25 to 15 cycles.

A higher output can be obtained from the series repulsion motor for the same reason as in the 15-cycle series motor, by working the iron to saturation. If the higher flux were obtained by increasing the field turns, the effect would be, as stated by Mr. Lamme, a decreased power-factor. The power-factor, h wever, does not depend upon the number of ampere-turns in the field, but upon the ratio between excitation and armature reaction. By abolishing the resistance leads and allowing more room for copper, the armature reaction can be increased simultaneously with the field excitation and without affecting the power-factor, and the increased output is gained by increased voltage as well as increased current.

Mr. Kintner gave some data on the wear of brushes, A number of equipments of this type have been in operation for some time, but I am sorry that I cannot give the ultimate life of brushes, because they have not yet worn out. Brushes that have been in service for 10,000 miles show a wear of $\frac{3}{16}$ in. and the brush looks like new, so that there is no other limitation to the life of the brush than the amount that it can be fed down in the holder. The commutator assumes a brown polish like that of a good direct-current motor.

Elmer A. Sperry (by letter): It seems to me, that Mr. Alexanderson's paper indicates an epoch-making advance in the art of railway-motor design. In connection with the remarks that have been made in reference to slipping versus non-slipping drivers, if I understood the remarks correctly, it was stated that the dead weight of the equipments for heavy traction work range so high that it is impossible to get motors with power enough to slip the drivers sustaining these weights. I take this theory of the locomotive to be almost revolutionary. I think there is no railroad superintendent who would consider a steam locomotive that could not easily slip her drivers as worth putting a fire into. I have been engaged for some years in designing and manufacturing locomotives for the most strenuous sort of work, and I remember reading a paper before this Institute about fifteen years ago, describing some aspects of these machines. I most cordially agree with Mr. Potter, that one of the most essential features, and one which must not be neglected in the design of a successful electric locomotive, is that it should be possible at all times to slip the drivers, even under conditions of heavy sanding. In this connection it might be stated that if it is considered important for the steam locomotive, it is certainly doubly so for the electric locomotive, where slip is necessary as a preventive of excessive overloading of the motors; this is a consideration of importance to us, but a point that does not in the slightest affect our competitor, the steam locomotive.

Several years ago we started to build rack-rail locomotives, principally for mine haulage. Since that time we have installed several hundred miles of this equipment and new installations are going on constantly. Here there is no safety-valve for the electric motor, no slipping has been possible, and we have had no little difficulty in adapting motors to this service. They have had to be designed and re-designed until a successful machine of to-day is, in case of emergency, able to slip the drivers, including the pinions up out of the rack, without damage to the motor. Leaving the rack occurs at a point between 180% and 200% of draw-bar pull.

I would emphasize what I have said, and add a note of warning to the designing engieer: a locomotive that can not slip its drivers will not be able to stand in competition with one designed easily to accomplish this function.

E. F. Alexanderson (by letter): Regarding Mr. Lamme's remarks concerning the use of resistance leads, I would say that in the series motor the function of the resistance leads is dual; first, to assist in commutation, and secondly, to help in starting. In the series repulsion motor the problem of commutation has been solved, and therefore the only field of usefulness for these leads would be at starting. If resistance leads were the only solution to obtain good starting, they would be used in the series repulsion motor, as series repulsion motor with resistance leads would give the same increase in rated capacities, and the same improvement in commutation, as would be effected by changing the frequency of the series motor from 25 cycles to 15 cycles.

The above statements are verified by actual tests. Messrs. Lamme and Storer have given examples of tests before the Institute, which show that a 100-h.p., 25-cycle series motor when operated at 15 cycles is rated at 125 h.p. Other tests have been made on a 75 h.p. motor operating as a series repulsion motor at 25 cycles, and operating as a series motor at 15 cycles. The results of these tests show that the heating was lower in the former than in the latter instance. Another series repulsion motor of 450 h.p. continuous output when running at 400 rev. per min. showed that the heating was only 5° cent. higher when operated on alternating current at 25 cycles than operated on direct current.

The characteristic curves given in Fig. 1 relate to the last named motor, and it may be of interest to state that this same machine has delivered 800 h.p. at 310 rev. per min. with almost sparkless commutation. An examination of the power-factor curve shows that its general nature varies somewhat from that of the series motor in being more constant through its entire range of operation, and it gives a speed curve more nearly resembling that of the direct-current motor than can be obtained with the series motor.

As this power-factor ranges from 90 to 94%, it certainly does not need to be apoligized for, as some the other speakers seem to think. If my remarks in the text of the paper are taken as apologetic, I must explain that I was comparing the power-factor of the series repulsion motor with that of the Latour-Winter-Eichberg motor, which at least is worthy of as much consideration as the series motor.

In answer to questions about the ability of the series repulsion motor to exert a torque at standstill, I reply that motors have been tested with the armatures blocked and have given double their normal torque for one minute. A large number

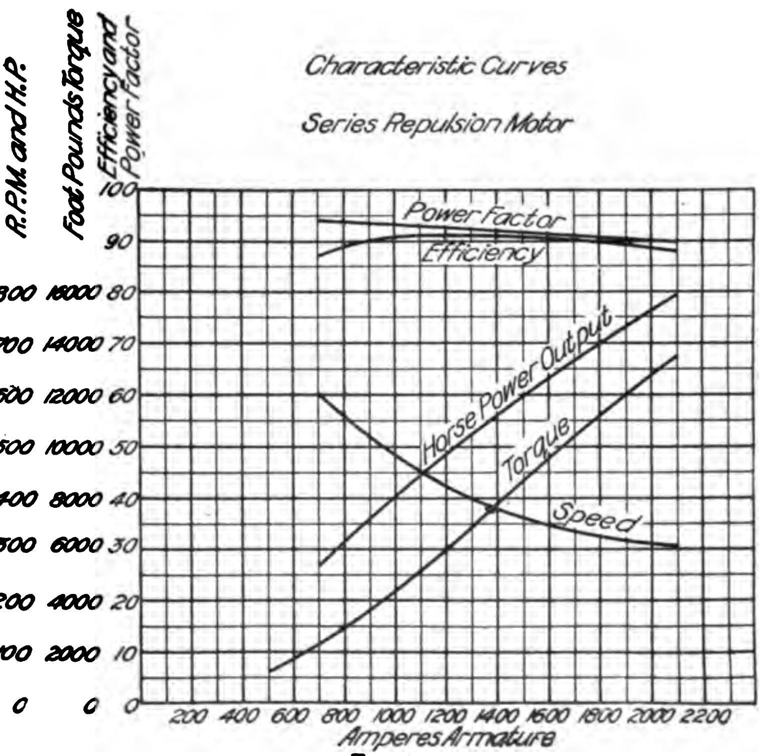


FIG. 1

of series repulsion motors are in operation without resistance leads and no difficulty has been experienced in starting, although these motors have not the improved features of starting which are referred to in the paper.

Actual tests that have been made will best serve to show the starting ability of these motors. On one occasion a train of 250 tons was hauled by four-motor equipments consisting of 125 h.p. motors. This train was started on a one per cent. grade, and as a further test two motors were cut out and the remaining two motors started this 250-ton train on the same grade.

A paper presented at the 224th meeting of the American Institute of Electrical Engineers, New York, January 10, 1908.

THE NEW HAVEN SYSTEM OF SINGLE-PHASE DISTRIBUTION WITH SPECIAL REFERENCE TO SECTIONALIZATION.

BY W. S. MURRAY.

The method and distance chosen for sectionalizing the high-tension wires supplying power for alternating-current traction is worthy of careful consideration. Local conditions play so important a part in the correct conclusion of method and proper distance to be applied, that no precedent or convention can be followed and standardization is quite out of the question.

In advance of taking up the concrete subject at hand, doubtless it will be of interest to touch upon several alternative distributing systems that were considered by the engineers of the New Haven road before the final adoption of the system of single-phase distribution and sectionalization now in service. Some of these were:

1. 11,000-volt, three-phase generation at the power house; transmission along the right-of-way at this voltage; step-down transformers furnishing trolley voltage at 3300; track mileage divided into three equal linear parts, each part being supplied by an individual phase.

2. The same arrangement as (1) with the exception that step-down transformers furnish 6600 volts to trolley.

3. 11,000-volt, three-phase generation at power house; transmission along the right-of-way at this voltage; track mileage divided into two equal linear parts, each part having its trolley connected through the transmission line to one of the three terminals of the power-house bus-bars, the remaining

bus-bar being connected to the tracks, thus making a common connection for the two trolley sections.

Diagrams 1, 2, and 3, Fig. 1, represent in the simplest form the three above described arrangements. It follows, of course, that

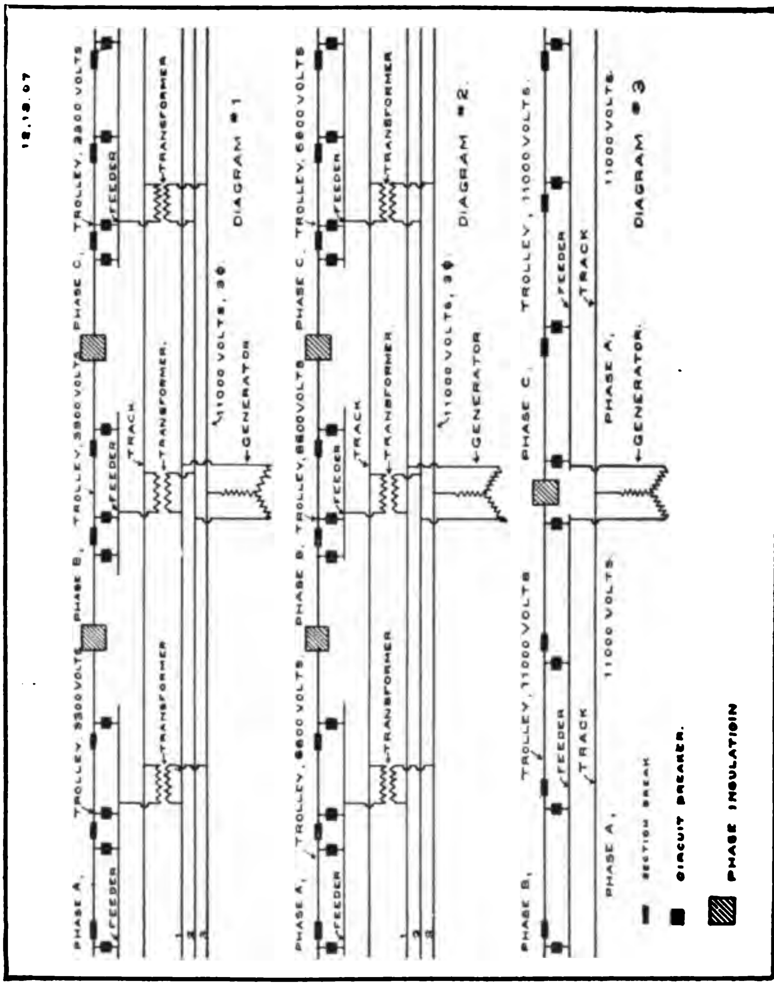
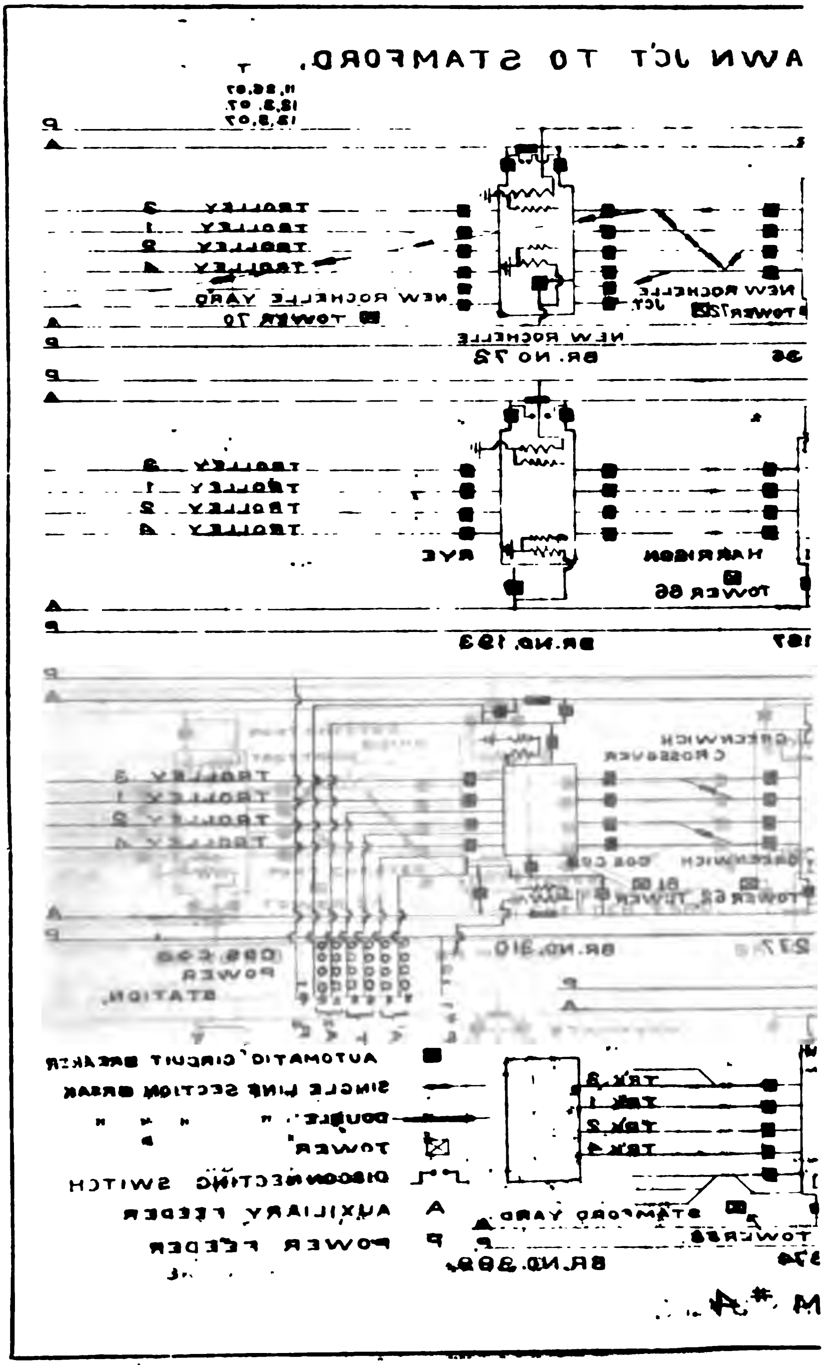
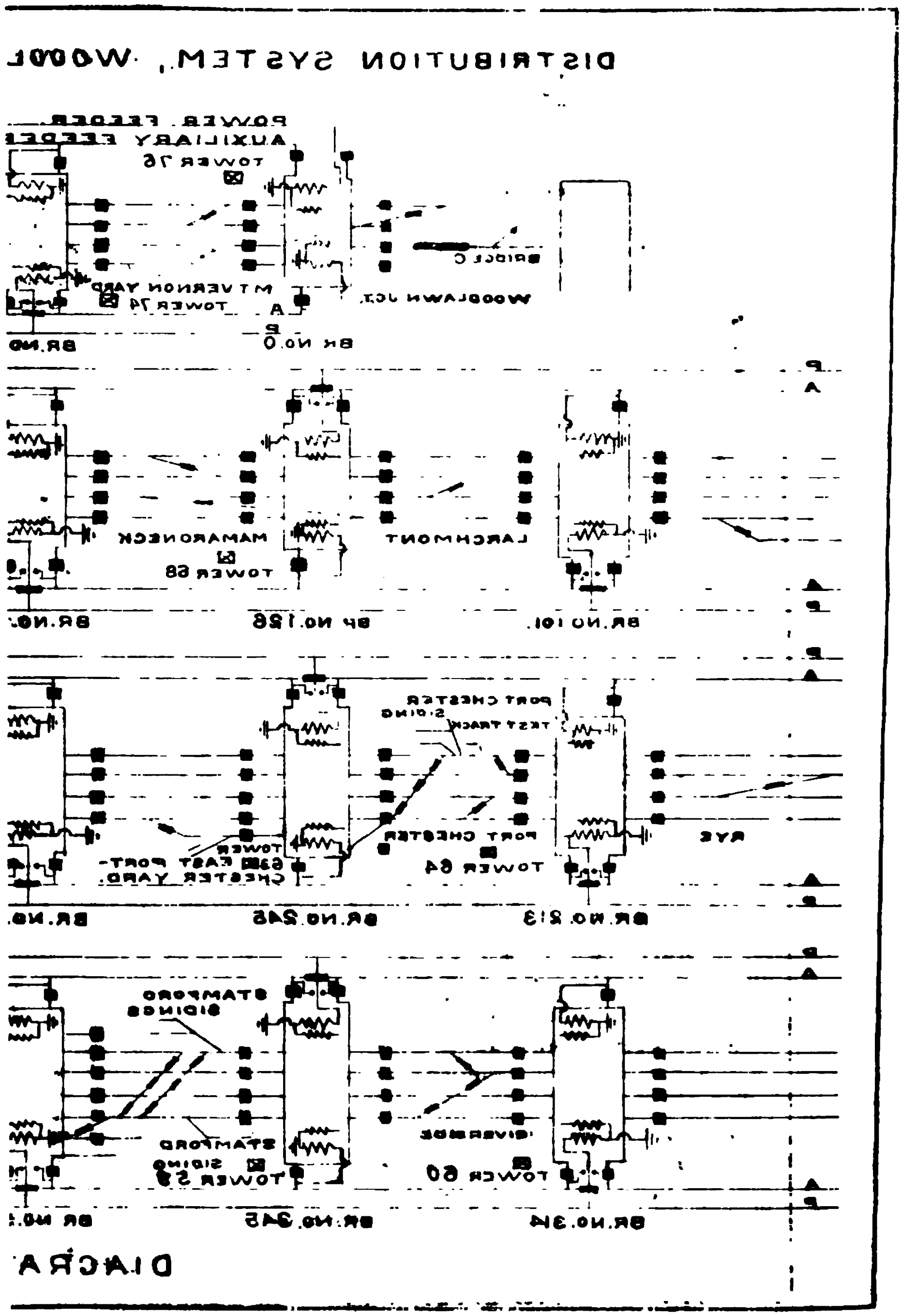


Fig. 1

the phased divisions in each case could be further individually subdivided into sections wherever desirable. The presentation of these three methods of distribution by no means prescribes the limit of combinations that mav exist, as many others of an interesting character have been suggested.



AWN JCT TO STAMFORD.
TROLLEY 3
TROLLEY 1
TROLLEY 2
TROLLEY 4
NEW ROCHELLE YARD
TOWER 70
NEW ROCHELLE
NEW ROCHELLE JCT.
TOWER 72
BR. NO 72
RYE
HARRISON
TOWER 66
BR. NO. 193
GREENWICH CROSSOVER
GREENWICH
TOWER 62
BR. NO. 310
POWER STATION
AUTOMATIC CIRCUIT BREAKER
SINGLE LINE SECTION BREAK
DOUBLE
TOWER
DISCONNECTING SWITCH
AUXILIARY FEEDER
POWER FEEDER
TRK 3
TRK 1
TRK 2
TRK 4
STAMFORD YARD
TOWER 58
BR. NO. 389


DISTRIBUTION SYSTEM, WOODL
POWER FEEDER
AUXILIARY FEEDER
TOWER 76
M T VERNON YARD
TOWER 74
WOODLAWN JCT.
BRIDGE C
BR NO 0
BR.NO
MAMARONECK
TOWER 68
LARCHMONT
BR NO.126
BR.NO.101
BR.NO.
PORT CHESTER SIDING
TEST TRACK
TOWER 63 EAST PORT-CHESTER YARD
PORT CHESTER
TOWER 64
RYE
BR.NO.246
BR.NO.213
STAMFORD SIDINGS
STAMFORD SIDING
TOWER 59
RIVERSIDE
TOWER 60
BR.NO.245
BR.NO.314
DIAGRA

Fig

4. 11,000 volt, three-phase generation, transmission along the right-of-way at this voltage, only one phase being applied to all sectionalized trolley wires throughout the zone of electrification. The three phases are also carried throughout the electrification zone, and are at all points available for polyphase motors, such as would be used in railway machine shops and for the operation of motor-driven generators in local direct-current railway plants owned by the railroad company.

In Diagram 4, Fig. 2, there is shown diagramatically the actual scheme of single-phase distribution which has been adopted, and is now in service.

There are advantages to be gained in any one of the above mentioned alternatives, but the single-phase distribution as described under 4 carries with it advantages, the sum of which far outweighs the sum of the advantages in the others. In a word, the distribution, as described under 1, 2, and 3, would seem to offer a better opportunity to distribute the load in the three-phase windings of the generators, and yet this is open to question on account of the possible unequal distribution of trains in the individual phased sections; but the greatest and deciding disadvantage to any of the three-phase distribution schemes is the complication that results in the overhead system, together with the fact that for an equal weight of overhead copper the efficiency of the single-phase system is higher than any of the polyphase arrangements. From the foregoing, I believe it will be generally conceded that the single-phase scheme of distribution is the best.

A modification of arrangement 4, which was considered, may be mentioned; namely, 11,000-volt, three-phase generation, single-phase distribution for traction with step-down transformers distributed along the line, their secondaries furnishing 3300 or 6600 volts to the sectionalized trolleys. For the reason that the life-hazard in using 11,000 volts was not considered to be greatly increased over that of 3300 or 6600 volts, and in view of the higher efficiency, lesser currents to be collected by locomotive shoe contacts, greater reliability, and the lower operating costs (no transformer sub-stations) the advantages of the 11,000-volt direct transmission to the sectionalized trolleys was immediately apparent, and the problem became simply one of insulation.

As concerns the choice of three-phase generators in connection with single-phase distribution for traction purposes, again local conditions were the real factors that framed this conclusion. Single-phase or balanced polyphase voltages are undeniably more desirable than unbalanced ones; at the same time when proper allowance and arrangement are made for the unbalanced voltages, and there is a decided market for polyphase power, it is difficult to escape the conclusion that it is a desirable and necessary adjunct to the system. In connection with its application to the New Haven electrification, it may be said that synchronous motors will be shortly substituted for steam engines in one of our lighting plants. Such arrangements will bring about the centralization of power generation, and by proper field adjustment of the synchronous motors the general power-factor of the single-phase system will be raised.

Having touched upon some of the determining factors that brought about the arrangement of three-phase generation and single-phase distribution, the remainder of this paper will be confined to a discussion of the methods and lengths involved in the sectionalizing of the single-phase distribution, and as the power wire (which is the outside wire marked *P* in Fig. 4) plays only an unimportant part in its applications to the traction system, it will not be referred to again.

An examination of the electrical connections made in and on the power-house, line, and locomotives would bring out the strong similarity of the New Haven System to the well standardized direct-current, (not alternating-current–direct-current) system. Indeed, I think it can be fairly said that the current in either case has the same path to follow, the only differences lie in the nature of the current (alternating and direct) and the voltage. In either case the path is from one bus-bar of the station to the feeder and trolley, thence to the locomotive and from there to the rail and return to the other station bus-bar. In the alternating-current system is noted, of course, methods of installation common to high-tension practice.

Single-phase distribution offers an excellent opportunity for sectionalizing. As may be seen in Diagram 4, Fig. 2, the system consists simply of the track trolleys, two auxiliary wires immediately adjacent, and the necessary switching complement. Although these auxiliary wires have been called feeder wires and while, as a matter of fact, they do serve to increase the capacity of the overhead system, this is not their principal function, as the amount of copper included in the trolleys would suffice to be within the economic figures of copper loss. The auxiliary wires are installed to serve as by-passes, in the event of it being desired to cut dead any or all of the trolley wires in any section. Thus by this system of auxiliary by-passes any degree of sectionalizing can be used, and any or all trolley voltages in sections can be removed without interrupting the continuity of the voltages throughout the zone.

The lengths of sections are governed entirely by local conditions. No two sections of the 14 that exist in the 21 miles of New Haven electrification are the same. It is seen, however, from these figures that the average length of sections is 1.68 miles, that none of these is over 2.19 miles or less than 1.07 miles.

The best reason that can be assigned for the use of sections is in order that line troubles may be localized. There are many others, and some of a most important character. Indeed, it may be said that were the line absolutely immune from trouble, such as grounding, mechanical failures, etc., there would still be many good reasons for sectionalizing it, and these reasons will develop as the subject is further studied.

One of the most attractive features of single-phase distribution is the elimination of sub-stations with their fixed and operating charges, and unlike the alternating-current–direct-current scheme of distribution, where the length of section is settled by the equation of load and copper to meet it, the single-phase system is not bound by these limiting electrical conditions. Line-loss is forgotten in the establishment of a mechanical construction, the amount of copper in which is only a fraction of the amount required for an equivalent loss for the same amount of power transmitted in the alternating-current–direct-current systems. This convenience of transmission with low loss permits sectionalizing *ad libitum* and the local conditions are accorded almost the entire privilege of decision. The advantage of such a relation between operation and distribution was immediately apparent to Mr. E. H. McHenry, Vice-president of the New York, New Haven & Hartford Railroad Company, whose suggestion that the electrical and train signal blocks be made co-terminus was adopted. It will be noted, then, that of the fourteen electrical sections between Woodlawn and Stamford, nine of these are co-terminus with the signal towers. In each of these towers, there is installed a small panel containing the pilot-switches controlling the trolley (and by-pass) circuit-breakers installed on the anchor bridges. Aside from the economical features of this scheme of control, as no operators other than our present signal operators are required, the value of placing the distribution in the hands of this class of men is most important, their constant attention to matters pertaining to the operation of trains bring about the attention which should be accorded to the distribution of current; their thorough understanding of the conditions of traffic on the various tracks permitting the most intelligent handling of electrified and de-electrified trolleys, assuring at once prompt and reliable service in the matter of handling a situation when cross-overs have to be made on electrified tracks, and while repairs are being made on others from which the voltage has been removed. The value of placing the distribution system in the hands of the signal operators may be again illustrated by saying that should an electric train run past a stop-signal set by the operator, or should the operator desire to stop a train in his block he has only to trip the pilot-switch controlling the trolley circuit-breaker, from which the train is drawing its power, and signal the operator in the adjacent tower to do likewise. The individual value of this protective perquisite is an illustration of the use of sectionalizing outside of the question of line troubles.

As before stated, it is impossible to elect some standard distance for sectionalizing the line and then apply it to a steam road undergoing electrification. It is possible to conceive of an entirely new electric line subjected to this hypothetical course of procedure, but even in this extreme case it is difficult to escape the exceptions that could be taken to it; for example, what a strange coincidence it would be to find fifty towns just two miles apart along a railroad's right-of-way. On the other hand, how important each town would be whereat to locate a signal tower with its complement of electrical equipment.

In the discussion of sectionalization it would seem proper, therefore, that instead of specifying the length of sections, to specify the number to be used over a given total distance; their individual length varying in accordance with the local conditions peculiarly related to them. Upon this basis, it will be interesting to enumerate the following advantages and disadvantages peculiar to a choice of a "small number" and a "large number" of sections over a given distance. In this table it should be remembered that usually the items of advantage for the "small number" of sections will be items of disadvantage for the "larger number" and vice-versa. Also it is assumed that the signal towers along the right-of-way average

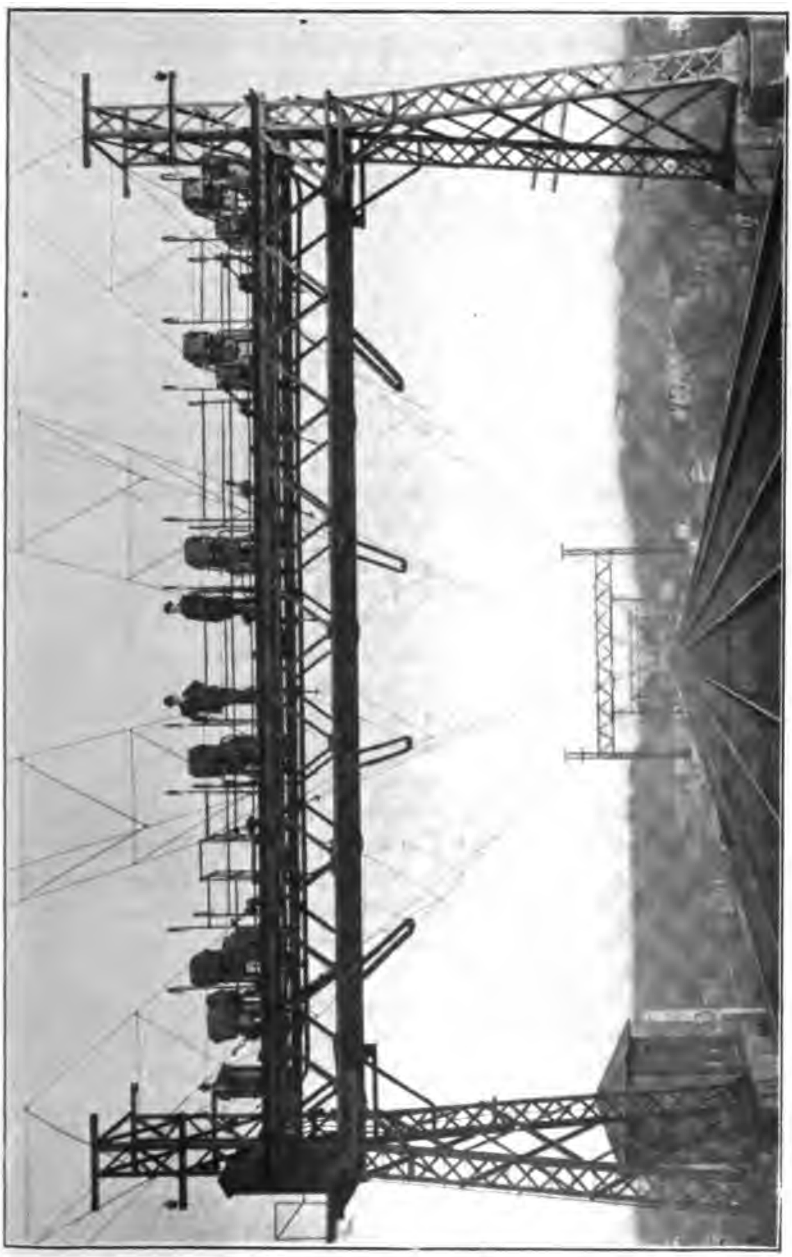


Fig. 3

about one and a-half miles apart and that electrical sections of this length, or longer, will be classed as a " small number " and sections shorter than this will be classed as a "large number."

A tabulation of the advantages and disadvantages of the use of a " small number " against a " large number " of sections is as follows:

SMALL NUMBER

Advantages	*Disadvantages*
1 Co-terminus tower scheme more easily arranged.	1 Difficulty of locating grounds increased.
2 Less switches to maintain.	2 Greater section of track cut dead in case of ground or other trouble. Disadvantage, however, related to cross-overs.
3 More reliable; due to less frequent grounding of line.	3 Larger section breakers required
4 Less cost.	

In advance of a discussion of the items in the above table it is fair to assume that convenience of construction of the apparatus required for either the long or short sections may be equated. That is to say, the work-train service, in either case, would be about the same, and the structures to be put up of a character which would require much the same general superintendence and engineering.

In the case of the long sections, it would, of course, be necessary to splice the messenger cables, as they could hardly be manufactured on single reels greater than two miles in length, but the splicing process would not be a matter of great inconvenience, and would not detract from the value of the cables.

On the other hand, in the case of the shorter sections a greater number of anchor bridges would be required for the supply of sectionalizing switches, but this form of structure would not increase, to any extent, the difficulties of erection, or would the placing of apparatus upon them interfere with regular traffic.

Taking up the discussion of the above tabulation of advantages and disadvantages for the small number of sections versus the larger number; or, stated in another way, sections of greater length versus sections of shorter length, we note that under " advantages."

1. *Co-terminus tower scheme more easily arranged.* In my estimation this is by far the most important factor favoring a small number of sections. It is quite clear that with a great number of sections, their termini would fall at points between towers, necessitating some form of substation or building for

the electrical operators. This would be inconvenient, both for the railroad company and the operator, on account of the cost of maintenance and operation for the former, while the latter would be far removed from his living point.

The reason that the co-terminus scheme is more readily arranged with the use of long sections is apparent, in view of the fact that no convention is necessary to be followed in regard to standard distances, it being at the option of the engineer to choose such towers as are already located on the line as a termini of electrical blocks.

2. *Less switches to maintain.* This advantage is immediately seen, in view of the number of switches being directly proportional to the number of sections, and I believe there is general agreement that a switch in any line does not increase the reliability of that line.

3. *More reliable; due to less frequent grounding of line.* At the present stage of the art, the anchor insulators, which have given the best results from a combined mechanical and electrical strain point of view, have been of corrugated cylindrical form. In this form their insulating value is unquestionably less than the mushroom or petticoat type of insulator, and experience indicates that they are very much less reliable than the mushroom or petticoat type (this form of insulator is used to support the messenger cables on intermediate catenary bridges). It is my belief, however, that by suspending some form of protective shield or petticoat from the anchor insulator, its insulating value will be greatly enhanced. The blast from steam locomotives seems to produce a very rough enamel of coal dust and cinders, which, on account of deeply imbedding itself in the insulator, is almost impossible to remove, in consequence of which insulating values are greatly reduced.

4. *Less cost.* It is immediately apparent that the cost would be much less on account of the elimination of a larger amount of switching apparatus and the heavy bridge work required at all anchorages.

In the table of "Disadvantages" we note:

1. *Difficulty of locating grounds increased.* This is quite apparent, in view of the fact that there are a greater number of insulators between the circuit-breakers, but experience in actual operation has indicated that this is not a serious matter, as the offending insulators are very quickly located, and there is also being perfected at this time a resistance scheme of measure-

ment by which the point of ground can be approximated within 5 % of its actual location; and upon the perfection of this apparatus this difficulty will be eliminated.

2. *Greater section of track cut dead in case of ground or other trouble; disadvantage, however, related to cross-overs.* This trouble would be of a more serious character if it were railroad practice to include a great many cross-overs on the main line. The average distance between cross-overs on the New Haven road is even greater than the distance of the electrical blocks; in consequence of this, should a section become dead on account of a ground, it is possible that the train would have to cross over at a distance from the trouble greater than the length of the electrical section. Railroad engineers look upon cross-overs as a necessary evil (remembering their high cost of maintenance, together with the necessity of interlocking machines in conjunction with them) and it is fair to assume that their distance apart will not be decreased for the convenience of shortening the electrical sections; hence, this difficulty cannot be classed as one of special moment.

3. *Larger section breakers required.* In the use of longer sections, it is apparent that more trains may be drawing power from the section breakers, in consequence of which it is necessary to design them for greater capacity and they will be called upon to open larger propulsion currents. The difficulty of this, however, fades in the maximum demand upon the breakers being a short circuit, and as this is a duty a section breaker of any capacity has to stand ready to perform, this objection might be considered as not existing.

It would be a strange state of affairs if it were impossible to improve upon any principle or form of construction adopted. In regard to principles which have governed in the electrification and sectionalization as adopted by the New Haven road, I have found by careful inquiry into the opinion of those who are responsible for the operation of our electric trains and the distribution of currents to them, that if any change were to be made, possibly some advantages would accrue in the use of a longer section.

In regard to form of construction. It is fair to say that there are many changes that can be and are being made, which will greatly increase the efficacy of distribution. It is my observation that the New Haven electrification has been looked upon as a radical departure from engineering practice. There is no question about the justice of such a remark when viewing the matter as a whole. If, however, we segregate each link in the chain which forms the whole, I believe it will be found that no one link is a particular departure from a practice that has existed many years. It has simply been the putting together of old principles into a new form. One exception can be made to this statement. The alternating-current railway motor is new, and yet an exposition of its characteristics, such as in its speed and torque curves, show that within it the old underlying principles prevail. Its complements, the power-house and line, involve no new principles that have not been tried out under various forms and conditions. A high-tension moving contact has nothing new or of a disturbing nature about it.

When the form of electrification of the New York division came up for decision, there was an easy path of the least resistance open to the engineers of the New Haven road. A form of electrification had been adopted and applied to traffic rails over which the New Haven trains were obliged to go in their entrance to New York City. An acceptance of this form of electrification would have simplified and made easy the duties and responsibility of the engineers of the New Haven road. The right path, however, is not always the easiest, and the principles which existed in their minds were of a character that required a radical departure from the easy and tempting alternative. There is an old saying: "Nothing that is worth while ever came easy," and such has been the case with the New Haven road. We have encountered unexpected difficulties, which are always common to initiative, none of them, however, has been of a character which could be interpreted as a menace to the general principles involved. The difficulties have either been corrected or their correction is easily in sight.

The last six months of operation have offered the opportunity for a collection of valuable data, and the following observations and recommendations are offered in the hope that they may be of some value to other engineers interested in the electrification of steam roads:

1. In one-, two-, three-, or four-track railroads, the single-phase distribution should include besides the trolley wires, by-passes or feeders.

2. Electrical sections should not average less than 1.5 miles in length; greater averages are entirely acceptable and individual lengths should be governed by local conditions.

3. Twenty-two feet is a safe general working distance of trolley from rail.

4. The de-insulating effect of steam locomotives stack discharges is a most important consideration to be kept in mind in the matter of properly insulating high-tension wires from ground.

5. High insulation factors should be used where high-tension construction due to low bridges is brought nearer the rails than the normal height of 22 feet. Strong mechanical shields should be used to deflect locomotive blasts from messenger insulators at low bridges. Care should be exercised in the installation of these shields so that high-tension conductors and ground are at safe working distance. Wherever possible insulators should be installed away from the direct line of the locomotive blast.

6. Auxiliary wires in connection with the electrification, if they cannot be carried over highway bridges as aerial conductors, should not be carried under, unless they are enclosed in lead-covered cables, with end-bells properly enclosed in suitable housings at points where the conductors change from aerial to lead-covered cables.

7. All circuit-breakers connecting feed wires (or by-passes) to the trolley bus-bars should be equipped with time-relays, so that any short-circuit will immediately open the trolley-breakers, thus locating the trolley section grounded. Equipping the feeder breakers with time-relays insures continuity of voltage on wires not affected by the short-circuit. Each trolley-breaker pilot-switch should be provided with a light to indicate when it opens, and an announcer bell should ring in the signal tower at the same time so that the operator is promptly notified.

8. On account of deleterious influences of weather and locomotive stack discharges, together with general inconvenience of getting at bus-bars and switches when installed on anchor bridges, all section oil-switches should be installed in switch houses erected at the side of the tracks, with lead-covered cable connections between trolley and switches.

9. Signaling should be arranged so that the operator can prevent the engineer from spanning two sections by his locomotive shoes in the event of the advance section being grounded.

10. All signal towers should be interconnected with a reliable telephone service. Immunity from electromagnetic and electrostatic disturbance in the telephone system can be secured by

using twisted-wire pairs enclosed in lead-covered sheath, the sheath being grounded frequently. This suggestion is more particularly applicable to the interrupted or tower-to-tower telephone system. In this case the distance of exposures of the telephone wires is not great, and thus the summated effect of electromagnetic induction is negligible. In the case of the through telephone line where the circuit is uninterrupted throughout the zone of electrification, again the lead sheath and twisted pair are respectively effective in removing all static charges, and electromagnetically balancing the circuit; but on account of the cumulative action of the electromagnetic induction, either compensating transformers or a system of impedance coils installed across the telephone circuits at intervals of two miles (this distance may be less, depending on the electromagnetic density) with their central points grounded should be used. Either method will satisfactorily remove the impressed voltage due to electromagnetic induction. The importance of reliable telephone service between operating towers cannot be too greatly emphasized.

The above mentioned are some of the fundamental requisites which design and practice have brought out in connection with the New Haven electrification. Design and practice are many times good friends, but if a difference of opinion arises, practice will, in nine times out of ten, have the better of the argument. Experience, the great teacher, has brought out either the efficacy of the original design or the proper modification of it.

The observations and recommendations above cited, are those that have been impressed upon the writer during the period of operation so far attained. Except for certain minor and easily remedied details, experience to date with the New Haven arrangement of single-phase distribution would indicate that the fundamental principles involved have been correctly applied.

DISCUSSION ON "THE NEW HAVEN SYSTEM OF SINGLE-PHASE DISTRIBUTION, WITH SPECIAL REFERENCE TO SECTIONALIZATION." NEW YORK, JANUARY 10, 1908.

W. S. Murray: A retrospect always reveals more than a forecast. A perusal of the paper indicates to me, as doubtless to you all, that what has been touched upon is only a small percentage of the interesting and valuable data that could have been included were it at the election of the author to give his undivided attention to the subject.

I shall not attempt to apologize for what the paper lacks, and can simply say that odd moments, particularly those occurring while riding on the trains of the railroad company, supplied the time during which the article was written.

There has been no attempt to go into either the electrical or mechanical specifications of the distribution system. These were all included in the several contracts existing between the railroad company and the manufacturers and contractors, the general outline of which covers all points bearing upon the physical performance of the material furnished. As far as it was possible to anticipate, various weather conditions were considered in the design of all parts subject to changes of temperature, to wind, and to ice formation. We have passed through several snow, ice, and wind storms, and combinations of these, and all the iron structures, messenger, trolley, and feeder wires, have satisfactorily demonstrated the factors of safety which were included in their design.

A description of the electrical and mechanical details of the distributing system of the New Haven road has appeared in the columns of the engineering papers. My aim to-night has been more to acquaint you with some of our experiences rather than our theories. Therefore, fully conscious of many glittering omissions germane to the subject, and counting on the discussion to bring them out, I shall read the paper. [Here Mr. Murray read his paper.]

The discussion of double or single catenary construction on main-line electrification was intentionally omitted from the paper. A choice of the one or the other must be a compromise of a great many considerations, the principal ones being the number of tracks to be electrified, and local conditions; but there is one fact that has been conclusively demonstrated to me, namely, either the trolley wire or the trolley shoe must be flexible, whether the construction be for main or for branch lines. Of course in the single catenary construction a flexible contact conductor is provided. In the triangular construction, the contact conductor is rigid. This requires a flexible shoe, which in a degree is secured by the spring pantagraph arrangement. Experience, however, has forced upon me the conclusion that the pantagraph must be still further supplemented by a light but strong mechanism which will insure flexible contact between the shoe and trolley wire, thus not offering a great deal of inertia in movement when the shoe meets the hard spots of the line which exists at the catenary hanger points.

A form of construction we have adopted in our East Port-Chester yard, in which the latitudinal catenaries are supported by cross-catenaries—in some cases spanning as many as ten tracks—has about it a great many attractive features, and I am not too sure that experience will not bring out the possibility of using the cross-catenary for main line work. Such an arrangement, if more frequently reinforced with cross-bridge anchorages such as now used in the New Haven electrification, will bring a lighter and cheaper construction, and possibly afford a greater opportunity in insulating the overhead system from ground. I can see no reason why single catenary spans need be made any less than those used in the double catenary construction, as the cross-rigidity that may be desired can be obtained by tying into adjacent latitudinal catenaries, all of which, of course, are subject to the pull-off construction at present employed. Of course there are a great many pros and cons about this, and again we are forced to the conclusion that to-day is not the time for standardization, as it will pay not to accelerate our conclusions at a greater rate than the operating evidence upon which they should be based.

Still another point that has not been touched upon in the paper, is the great flexibility offered in the double-switch arrangement of supplying power to a trolley wire at the two extremities of its section. It is readily seen that if trouble exists in one of the circuit-breakers supplying a trolley wire in any given section, this switch can be immediately cut out and all the power supplied from the remaining switch at the other end. This flexibility, of course, is secured in virtue of the low loss due to high-tension transmission, and the employment of by-passes or feeders, to which previous reference has been made.

An impression has come to me that I might have dwelt more fully on the details of the system of distribution. As stated previously, it has been so universally described in the engineering papers that I have felt as if I were writing about results and experiences with something the general parts of which we were all acquainted. If I have universal support in this impression, I can only offer in amelioration, Diagram (4), which assembles all the links of our transmission chain, the functions of any one link of which are common knowledge.

L. B. Stillwell: I have not found time to read Mr. Murray's paper carefully, and I do not propose to criticize the sectionalization of the New Haven and Hartford trolley or its feeder layout. I have a very high opinion of the importance of these parts of the plant, which unquestionably are too often neglected. There are cases where very large investments have been made to insure continuity of service in which, judging by results, the investment has not been made in the right place. Instances might be mentioned in which, at great expense, excess generating capacity has been installed adequate to take care of the service, even in case of destruction of 50 per cent. of the total generating plant, and yet when the feeder layout was under consideration oversights apparently have occurred as the result of which very severe interruptions of service have followed. Unquestionably, therefore, criticism of the organization of supply circuits for large distributing plants, particularly for railway service, is highly beneficial. I say particularly in railway service, because in industrial power service the interruption of a feeder now ordinarily involves only a local and a very temporary failure of service; whereas in railway operation if we stop trains on one part of the line we are liable to hold up the entire operation of the railway.

W. B. Potter: The ordinary 600-volt trolley line is of little value as a standard with which to compare the 11,000-volt catenary under steam railroad conditions. Considered as an example of good construction, I have never seen the equal of the catenary to which Mr. Murray refers. As to the relative reliability and maintenance of such an overhead high-voltage trolley compared with a 600-volt third-rail, under conditions necessitating joint operation with steam, I believe this to be a debatable question.

I agree with Mr. Murray as to the desirability of a through feeder in parallel with the different sections; I do not see the need, however, of two such feeders on the same phase as the trolley wires. For local power the combination of the single feeder with the trolley wires would seem sufficient reserve. If any accident involved all four of the trolley wires, it would probably include the feeder as well; in case it did not, a single feeder could supply power beyond the break.

As to the length of the main-line sections, I favor from three to five miles, rather than less; as this question affects the reliability of operation, it seems that a reduction in the number of switching appliances would be favorable. Five-mile sections have proved satisfactory in third-rail operation, and there appears to be no reason for shorter sections with the high-voltage trolley, unless it is the greater liability of the longer sections to break down. It seems desirable, however, that at track cross-overs there should be a short section controlling the main-line and cross-over tracks, the better to insure cross-over movements in the event of interruption on the main-line sections.

Twenty-two feet seems to be a generally recognized standard height of trolley wire. It is unfortunate that this height cannot be maintained throughout, as it would then be possible to use a much lighter form of pantagraph. Overhead bridges, with their limited clearances, often necessitate a vertical movement of the collector of from seven to eight feet, and this condition requires a pantagraph structure more liable to derangement.

Depreciation of the catenary insulation from steam locomotive smoke would naturally be expected, and the extent of trouble from this cause seems to have a bearing on the permissible trolley voltage. Conditions might well arise where either copper or efficiency would have to be sacrificed for reliability.

The suggestions with regard to time-relays and switch indication are in line with well established practice. As to the method of operating the circuit-breakers, I understand that they are at present controlled from the main power circuit. Should not some means be provided for operating these switches in the event of failure of power? As these circuit-breakers are near signal towers, where manual operation could be conveniently applied, would not this be the more reliable method? Lever connections would provide certainty of operation and would not interfere with the automatic tripping. The proposed change from the bridges to switch houses would simplify the mechanical connections.

There is no doubt as to the desirability of guarding against the spanning of two trolley sections, as there is always the possibility of one section being grounded. Such accidents will occur. If the two pantagraphs or trolleys are far enough apart to span the section insulators, the only safeguard seems to be a fuse located between the two collectors.

O. S. Lyford, Jr.: Mr Murray's paper is written from the point of view of operation of a multiple-track road: when viewed from the standpoint of single-track operation, this subject has some rather different aspects. For instance, Mr. Murray says:

1. In one-, two-, three-, or four-track railroads, the single-phase distribution should include, besides the trolley wires, by-passes or feeders.

I do not take exception to this statement as relating to two-, three-, or four-track roads, but it does not necessarily apply to single-track roads. The objects of sectionalization are three: first, to minimize the interference with the operation of the road in case of line trouble; secondly, to locate the fault quickly; and thirdly, to reach the fault with a work train.

As to the first object, to minimize the interference with operation, I think it is quite apparent that a parallel feeder is not of much use as a by-pass in a single-track road of moderate length. Take, for illustration, the Erie road south from Rochester, Fig. 1. This is a single-track road, running from Rochester to Mount Morris. Power from Niagara Falls is received at a sub-station at Avon. At present the lines north and south from Avon are operated as two legs of a three-phase system, the common point being connected to the track. Avon is a junction-point with an east and west line of the same road. Rochester is about nineteen miles from Avon, and Avon is about fifteen miles from Mt. Morris. With a schedule speed of about twenty-four miles an hour and hourly service in each direction, it is apparent that a dead point anywhere on the line will, in a few minutes, block all trains on one side of the junction. The ability to move trains up to the dead point will not materially help the service.

The Erie line is divided into sections, but the principal object of sectionalization is to locate the fault quickly. The section breakers are " jumpered " through hand-operated switches and are placed near passenger stations or signal towers. If there is trouble, the system operator, by telephone orders, can have the section switches opened in sequence and quickly locate the section on which the trouble occurs. Mr. Murray speaks of special apparatus being developed to test for faults and locate them quickly. If such apparatus be produced, it will probably be more convenient than the use of section switches.

Considering the third object—to reach the fault with a work train—even with short sections such as have been discussed to-night, the work train, if operated by trolley, could not get within three-quarters of a mile or so of the fault, and it would be impracticable for the men to have to go the rest of the way on foot to make the repairs. The logical conclusion, therefore, is that the work train should be operated by an independent unit, either a steam locomotive or a gasolene car, preferably the latter, because it is more easily put in service.

Independent operation of long sections between important points is desirable. Usually, however, this will be best accomplished by high-tension feeders, rather than by by-pass feeders operated at the trolley voltage. The Erie system has been planned so that if the electrification is extended beyond the limit for economical transmission at 11,000 volts (for instance from Mt. Morris to Dansville) the present transformers may be connected so as to obtain either 11,000 or 22,000 volts, and 22,000-volt feeders may be carried to the distant section, serving the trolley wire through autotransformers. This plan allows transmission at double voltage and saves copper without appreciable complication.

Another case may serve to illustrate the conditions which arise in single-phase operation. The Denver & Interurban Railroad line from Denver to Boulder has a single-track main line and two single-track branches (see Fig. 2.) The power house is about 2 miles from the Louisville branch and 5.2 miles from the junction point. Power is supplied over two feeders from 11,000-volt, single-phase generators to the junction point. The length of the Marshall branch is 12.8 miles, Louisville branch 12 miles, and the Denver line 15.2 miles.

In this case it is obvious that there will be material advantage gained by being able to operate each branch independently, and provision has been made accordingly; but by-pass feeders for each branch would not help matters much in case of line trouble. The trolley wire, in this case, as with the Erie, has been provided with section breakers placed about 4 miles apart for convenience in locating faults.

There are other things to be taken into account besides the actual line trouble; that is to say, the problem is not merely to locate and repair the fault. On any railroad provided with

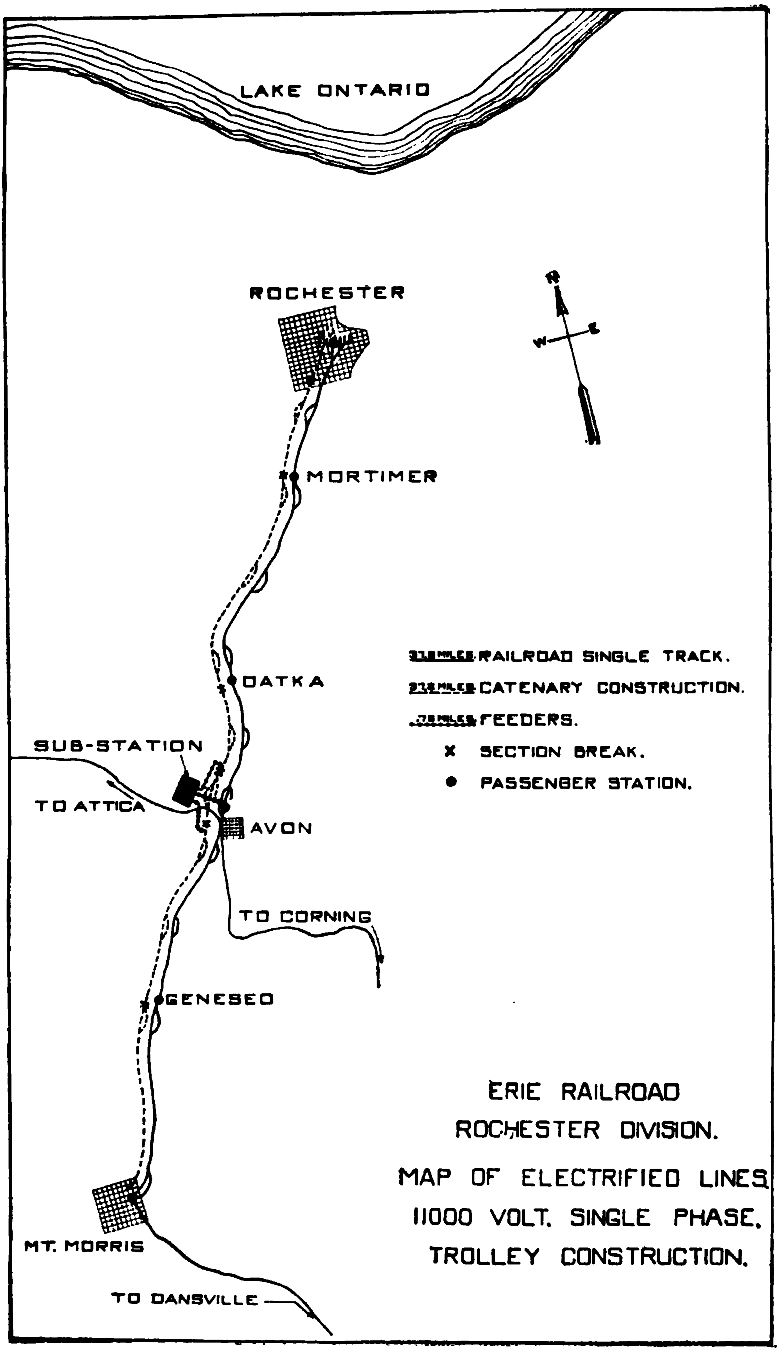

LAKE ONTARIO
ROCHESTER
MORTIMER
OATKA
SUB-STATION
TO ATTICA
AVON
TO CORNING
GENESEO
MT. MORRIS
TO DANSVILLE
RAILROAD SINGLE TRACK.
CATENARY CONSTRUCTION.
FEEDERS.
X SECTION BREAK.
● PASSENGER STATION.
ERIE RAILROAD
ROCHESTER DIVISION.
MAP OF ELECTRIFIED LINES
11000 VOLT. SINGLE PHASE.
TROLLEY CONSTRUCTION.

FIG. 1

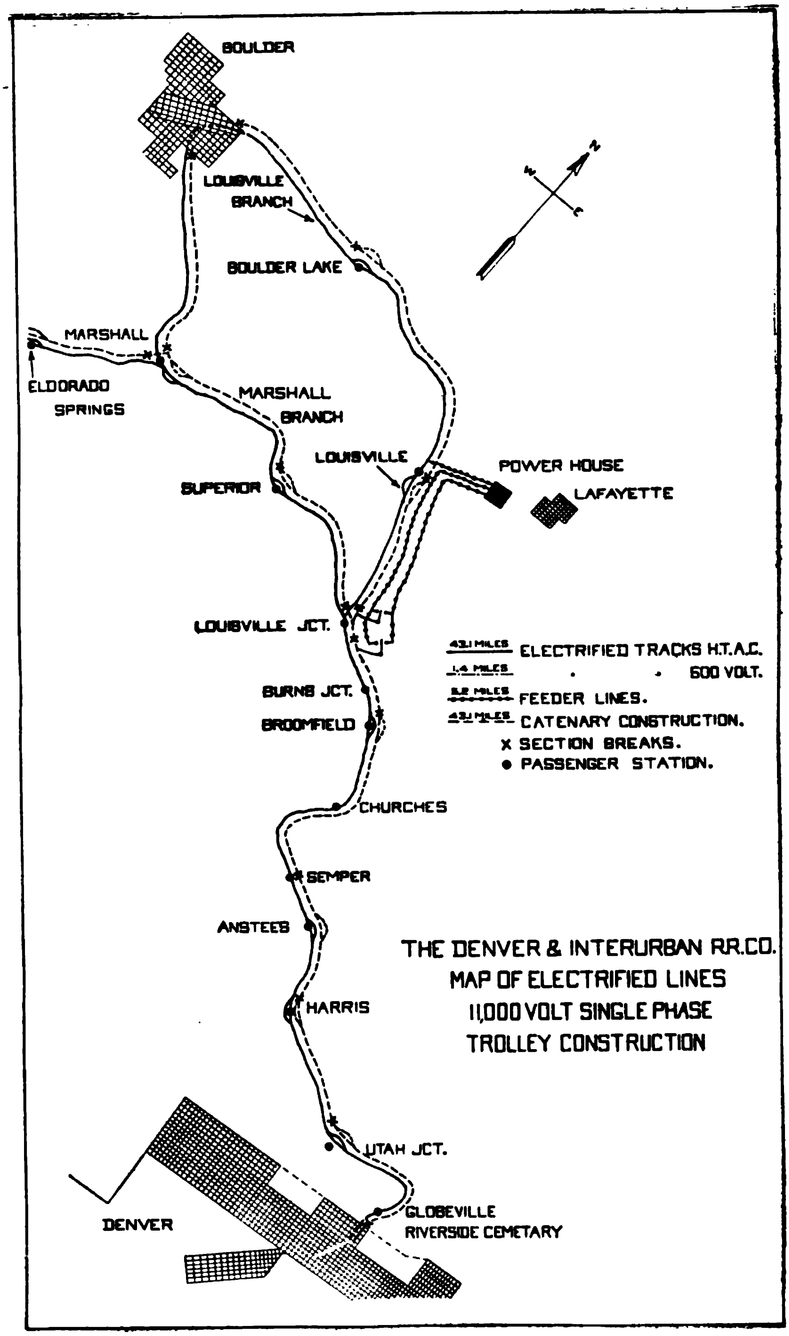

BOULDER
LOUISVILLE BRANCH
BOULDER LAKE
MARSHALL
ELDORADO SPRINGS
MARSHALL BRANCH
LOUISVILLE
POWER HOUSE
LAFAYETTE
SUPERIOR
LOUISVILLE JCT.
BURNS JCT.
BROOMFIELD
43.1 MILES ELECTRIFIED TRACKS H.T.A.C.
1.4 MILES " " 600 VOLT.
5.2 MILES FEEDER LINES.
43.1 MILES CATENARY CONSTRUCTION.
X SECTION BREAKS.
● PASSENGER STATION.
CHURCHES
SEMPER
ANSTEES
HARRIS
THE DENVER & INTERURBAN RR.CO.
MAP OF ELECTRIFIED LINES
11,000 VOLT SINGLE PHASE
TROLLEY CONSTRUCTION
UTAH JCT.
DENVER
GLOBEVILLE
RIVERSIDE CEMETARY

Fig. 2

a positive block system, the process of having the rules set aside so that a "special" can proceed against the block is about as difficult as to repair the fault itself. Most of the time of a service interruption is consumed in reaching the fault, not in locating or repairing it. Sectionalization does not help this part of the problem.

The natural answer to all of this is that the high-voltage trolley system must be put up so that line troubles rarely occur. That looks like quite a task with 11,000-volt operation, but as one gets acquainted with this high voltage construction most of the difficulties disappear. One important feature, according to present practice, is the exclusive use of porcelain for insulation. At first it looked as if the porcelain could not safely be subjected to the heavy physical strains of the catenary construction, but it has been found that standard forms of insulators, when properly harnessed, can be tested out with 14,000 lb. compression and 22,000 volts electrical strain at the same time. Thus far the physical strains in the catenary circuits do not exceed 5,000 lb. per wire, and there will be a factor of safety of about three for an insulator in a single wire or half that, if one insulator is used for both messenger and trolley wires. The use of built-up insulators is not promising. The use of wood, although the wood may be a good insulator, has the objection that if there be leakage across the wood and the wood be burned in two, then down comes the catenary construction. With porcelain properly harnessed, the only result of a broken insulator is reduced insulation. The line does not come down, because the harness is interlocked. With two insulators in tandem, the line will remain operative.

Mr. Murray's third recommendation of 22 ft. for general working distance of the trolley from the rail, seems to be about right, as has been said once or twice this evening, and this means a standard clearance of 24 ft. above the rail for the "through" and "under" bridges, and still greater clearances for other overhead structures, whenever physical conditions permit. In a large majority of cases (barring tunnels and city street-crossings) new construction can be designed for 24 ft. clearance without much difficulty or material effect in cost. The troubles of the electrical engineer will be materially reduced if the railways will make this the standard clearance for new construction.

The feature of high insulation factors for construction under low bridges should be characteristic throughout the entire installation, for the reasons which I have given. There is no reason for not having such an insulation factor.

Mr. Murray also speaks of the auxiliary wires passing under bridges, and advises the use of lead-covered cables with end-bells. A short section of insulated cable, in a grounded sheath, in the middle of a long overhead line, is a mighty difficult thing to install properly so that the insulation will not be frequently broken down. Inasmuch as the trolley wire has to go under the bridge, and the trolley must be bare, it would seem possible to put the auxiliary wire under the bridge in much the same way, and with equal safety.

One gratifying feature about catenary construction erected on grounded brackets or grounded bridges is that there are grounded structures close to and frequently above the live wires, and consequently little probability of disturbance from lightning. The Rochester division of the Erie road has been in operation for about eight months, and through nearly all the lightning season of last year there was practically no disturbance on the 11,000-volt system due to lightning, although there were bad thunder storms through that district, and a nearby high-tension line was struck repeatedly. On the other hand, in the single-phase system there occur occasionally heavy disturbances resulting in surges approximating lightning in severity, and if anything but porcelain be used for insulation (for instance, in the case of lead-covered cables above referred to) I should anticipate that such surges would occasionally break through the insulation.

On this Rochester division there is a telephone system on the same poles with the trolley line. With proper transpositions and suitable means for removing the "static" from the telephone line, it operates satisfactorily and without shock to the operators.

W. S. Murray: I am happy to feel that Mr. Stillwell bears me out along the ideas of a practical investigation. I think that mental reservations on this floor, where our mistakes may be brought out and discussed, is a great error. Our mistakes teach us more than our theories, and I think this floor is the place to discuss our troubles as well as our successes.

Mr. Potter spoke of pinning his faith to the third-rail instead of the overhead construction. In regard to that, I can simply say this is a problem much larger than the one we are discussing to-night; but I have reason to believe that on long-distance traction work the question of operating expense will unquestionably be the paramount feature, and hold the overhead construction and alternating-current transmission direct to motors a necessity. I can almost say that experience bears me out in this regard, even within restricted zones of electric traction.

I think that the necessity of two feeders can be explained quickly by saying that in the event of trouble the interlocking of the feeder system as established on the New Haven road is such that if trouble occurs on one feeder, by by-passing around through switches on the anchor bridges we are enabled to cut out any feeder-section and make repairs, thereby giving a more reliable continuity of service.

I thoroughly agree with Mr. Potter that the sections should be greater in length. I think that from three to five miles sounds reasonable, but local conditions govern better what the actual distance should be. I am quite convinced that were we to draw up specifications for the New Haven electrification again, I would be in favor of a longer section. This, as brought out in the paper, does not interfere with the conterminous arrangement of towers, which is most important.

In regard to pantagraphs operating under low bridges, Mr. Potter has brought out an important and deleterious feature of the overhead system. It is a problem that must be solved. We first started our electrification by a system of supports under low bridges, at very short intervals, and the result was, due to the effect of the locomotive blasts, that grounds developed very rapidly. This trouble has been overcome by eliminating the large number of supports, resorting to only two; and, instead of having the insulation in the middle point directly over the track, as at first installed, it has been placed at the side, so that the locomotive blasts do not affect the main insulators. Since we changed the construction to the latter arrangement, we have experienced absolutely no trouble in the grounding of the contact conductor (or messenger cables which are connected to it) under low bridges. This form of construction has been in use for four or five months.

In regard to the fact that for mechanical reasons we have to increase the copper in overhead construction high-tension work, the fact also must not be overlooked that the total copper is still in a minute ratio to the amount of copper required for an equivalent amount of power with the same loss transmitted on the alternating-current—direct-current system.

Operating the anchor bridge switches by levers would bring an increase of operating cost. I do not approve of this, particularly as lever arrangements in switches have been abandoned as cumbersome in places where quick action is required, and such a place as the operating towers calls for quick action.

In general, I agree with Mr. Lyford about the single-track feeder arrangement. In its application to long distances, however, I think a feeder arrangement for single-track construction is quite necessary, particularly where the headway is short and the traffic heavy. Should such trouble as he spoke of develop in the middle of the line, it is not uncommon in railway practice to operate to that point on both sides. In such a contingency the feeder or by-pass offers quick relief; it is not costly, and is constantly saving power. I certainly agree with him in regard to porcelain insulation in the place of moulded material, if it is possible to obtain the tension and compression strains in porcelain that is obtained in molded material.

Mr. Lyford's suggestion to use the same form of feeder construction under low bridges as is adopted in the trolley is a good one, provided the clearances can be obtained under the low bridges in question. Abutment walls are so near to the tracks that it becomes a rather difficult thing to put in this kind of construction, especially if, besides feeders, other wires, such as power wires and signal wires, have to be taken care of.

A paper presented at a special meeting of the American Institute of Electrical Engineers, New York, January 24, 1908.

THE BEST ENGINEERING EDUCATION

AN INTRODUCTION TO A DIGEST OF THE PAPERS ON ENGINEERING EDUCATION IN THE TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, WITH A VIEW TO RENEWED DISCUSSION OF THE POINTS CONTAINED THEREIN

BY CHAS. F. SCOTT

The recent rapid development of the electrical industry owes its vitality to the engineering school. Its graduates have done the designing, constructing, operating, and directing which have made possible the rapid progress and wide extension in the use of electricity. The ideals, the equipment, and the methods in engineering education, as well as the number and size of the schools, show a remarkable rate of progress. In fact, the advance in the electrical industry, in engineering education, and in the American Institute of Electrical Engineers closely correspond when measured numerically. There has been a close interrelation between them.

The future prosperity of the industry and of the Institute depends upon the efficiency of engineering education to an extent which one realizes more fully the closer he studies the subject. It well merits our best thought.

A review of the papers which have been presented to the Institute on engineering education shows that among our modern professors there are those who are active and alert and up-to-date. There is a marked agreement between the teaching profession and the engineering profession, both in an appreciation of the importance of the subject and in the general purposes which the engineering school should aim to accomplish. As engineers, it is quite unnecessary to argue that our schools should be more efficient and that their graduates should be better equipped for the work they are to do, as the professors are urging us to tell them how to accomplish these very objects.

Before discussing how to do something, it would be well to decide what it is we desire to do. What do those who use engineering graduates want them to be able to do? Ideas have varied. Some expect trained artisans, others trained engineers who are ready at once to do any kind of engineering work. Some expect technical specialists; while others call for men of ability who have a general preparedness for doing any kind of work. Some are disappointed if graduates are not immediately productive; while others provide courses of practical training. As all boys are not alike, and as their future employers have different ideas, and as their jobs will not be the same, it reasonably follows that there is room for more than one kind of training in college. The problem is not wholly abstract; it is vitally concrete. Its solution is not a rigid and narrow one, but it involves general policies. The details of method are to be determined by varying conditions and are to be adapted to the varying personal qualities of the young men.

In general, instruction in engineering schools is of three varieties:

a. Practical or industrial.

b. Scientific.

c. Cultural.

Practical or industrial studies are intended either as illustrations of scientific principles or as a direct preparation for business or professional life.

Scientific studies are the foundation for the applications and make the latter possible.

Cultural studies broaden the student's mental horizon, offset the narrowing effects of technical studies, and prepare for activities which are not purely technical.

The best engineering education is that which fits the individual student for his largest development and usefulness *in the long run*, not necessarily immediately after graduation. The problem, therefore, is to divide the four years spent in school among the three classes of studies in such proportion as will bring about the best results.

The problem is largely one of elimination, as, if all the studies were included which have been suggested as being essential or desirable in the training of an engineering student, the college period of 4 years would have to be increased to possibly 20 or 30 years.

Among the questions which arise in the discussion are the following:

1. The desirable characteristics of the acceptable graduate with respect to:

a. Practical familiarity with electrical apparatus which will enable him to be immediately useful, versus a less practical and more general training, which is to be supplemented by an apprenticeship course or its equivalent.

b. Specialized technical training and technical knowledge, versus a broader education aimed to develop intellectual power rather than the acquisition of technical knowledge.

2. The arrangement of subjects and courses which will best produce the desired results. The following questions arise:

a. The relative attention to be given to the practical or industrial, the scientific, and the cultural.

b. The relative proportion between subjects which are valuable for imparting technical knowledge and those affording training in scientific and logical methods.

c. The relation between school instruction and practical work; whether one should precede the other, and if so which one should come first, or whether they should alternate once a day, once a year, or at some other rate.

d. The importance of current engineering practice; of lectures by practising engineers; of discussion of current topics in local meetings of the Institute.

e. The degree of desirable differentiation in courses or methods on account of differences in the characteristics of individual students or in the fields of work they expect to enter.

f. The sequence of subjects—whether the theroetical groundwork should be laid during the first few years and the practical subjects reserved until the latter part of the course, or whether an intermingling of the two in accordance with the concentric method outlined by Professor Karapetoff is to be preferred.

I venture the prediction that the solution which will find most general acceptance will be that which gives to each student the training which fits him for his largest individual development; that for those who are qualified to take an active rather than a passive attitude toward their work the broader education, which emphasizes training rather than knowledge, will be chosen; that a fairly intimate intermingling of college work with practical work will be found to conduce to the efficiency of each, and that the field in which the greatest difference of opinion will be present will be with regard to the proposed concentric method. This system clashes with time-honored educational ideals, but it presents arguments which are so rational that the existing method must assume the defensive.

Those who were present at the Niagara convention will recall that the discussion on the papers of Professors Norris and Karapetoff was one of the most animated during the convention, and that it was brought to a close only on account of lack of time, although it had continued for nearly an hour after the ordinary hour for adjournment. It was the interest in this discussion which led to the appointment of an Educational Committee by the Institute, and which has led to the present summary (prepared by Professor Norris, chairman of the Educational Committee) of the educational papers in our TRANSACTIONS as a basis for the active continued discussion of this important subject.

DIGEST OF INSTITUTE PAPERS ON EDUCATION

1892. ANNUAL CONVENTION, CHICAGO

Robert B. Owens. The first formal paper on engineering education was presented by Professor Owens under the title, " Electrotechnical Education ". The value of the manual element is emphasized and attention is called to the departments of mechanic arts which had been attached to the Massachusetts Institute of Technology, the Washington University, and others. A technical school [according to the author] is primarily a place for the preparation of men who expect to earn their living as engineers. It is not a school of general culture nor is it a school of exact science. It is a device to save time, and teaches the application of pure science to industrial purposes. It is also a post-graduate school, and in this respect should rank with schools of law and medicine. Professor Owens at that time advocated the employment of a number of specialists in order that each student might have the opportunity to choose the work for which he is best fitted. While it is expensive to supply such specialists, and the equipment to enable them to carry on their work is costly, on the score of economy no more profitable expenditure of money is possible than for the support of technical schools Education is not a money-making business, and can never be made to pay for itself.

Professor Owens outlines the elements of a course in technology, basing his recommendations upon the existence of three kinds of electrical engineers—" installing engineers, designing engineers, and engineering scientists ".

Dugald C. Jackson. The technical education of the electrical engineer is one that should continue through life. Professor Jackson confines himself to a small part of this education, namely, the college education, and in order to be perfectly definite, he first outlines the course at the University of Wisconsin. The underlying principle is to depend on fundamental theories, with a common-sense view to their particular applications, in such a way as to aid in diagnosis, not by the application of a mathematical formula, but by comparing the accumulated experience of the practical world. It is comparatively easy to teach the fundamental theories, hence it is frequently overdone It is not so easy to educate the judgment of a student in electrical engineering, whose entire knowledge of his future profession is acquired from the electric bells in his father's house, and who may never have examined a dynamo, or storage-battery until he visited the college laboratory. Professor Jackson deplores the effect of the rigid specialization required in the technical school, and recommends a preparatory arts course when such is possible, and outlines the elements of the technical part of the course. It is interesting to note that in the paper delivered by him 11 years later he has not materially changed his views.

The discussion upon these two papers indicates the real interest taken in the subject at that early date.

1902. ANNUAL CONVENTION, GREAT BARRINGTON

Between the years 1892 and 1902 practically no attention was paid to the subject of technical education.* In the latter year, a session of the annual convention was devoted to this subject.

Chas. P. Steinmetz, in his presidential address, called attention to the fact that all future progress in science and engineering depends upon the young generation, and to insure an unbroken advance it is of preeminent importance for the coming generation to enter the field properly fitted for the work. Here the outlook appears to him by no means entirely encouraging. The proper function of the educational institution is to give the student 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 for the inefficiency of the college course is the competition between colleges, quantity having been increased at the expense of quality. Memory is developed at the expense of the reasoning faculty, and the college courses would be improved if one-half or more of the material taught should be dropped from their curricula, and the rest taught so as to be fully understood with reference to general principles and methods.

One objectionable feature of the instruction at 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 the examination it is dropped and another subject is taken up. To understand a subject thoroughly requires several years' familiarity with it, so that

* A. A. Hammerschlag prepared a paper in December 1898 on the subject of the education of electrical apprentices and foremen. This presented in an excellent manner the importance of properly training a class of men who could never be electrical engineers in the sense of their being technically trained. This paper is not abstracted here, as it is not in line with the general purpose of the resumé.

the study of any subject which is not kept up during the whole college course might just as well be dropped altogether.

The present method of examination, which consists in expecting a student to answer ten questions or so in a few hours, is faulty. It shows what the student has memorized, but not how far he understands the subject. In electrical engineering, nothing beyond the general principles is needed for success; time spent in memorizing things to be forgotten afterwards is entirely wasted.

Dr. Steinmetz outlines the ideal course in electrical engineering, advising a good foundation in elementary mathematics, with no memorizing of integral formulas which can be looked up in a reference book when required. A thorough knowledge of science, including physics and chemistry, both theoretical and applied, is strongly urged. Electrical laboratory work should be taken up from the start, even before the theory is understood. Design of electrical apparatus is of secondary utility, and rather objectionable, with the exception of some very simple apparatus. Far better is the reverse operation, the analytical investigation of existing apparatus.

Samuel Sheldon called attention to the necessity for uniformity in electrical engineering courses, pointing out the wide difference in practice in various institutions; for example, engineering students at Cornell University spend ten times as much time on shopwork as those in the Massachusetts Institute of Technology. The range in the various subjects in terms of hour units* are in mathematics from 5 to 11; drawing, 3 to 10; physics and chemistry, 7 to 25; English, 0 to 11.3; French and German, 0 to 10; shopwork, 0 to 21; electrical engineering, 9.5 to 23.8; other engineering, 7.7 to 23.2; thesis and elective, 0 to 7.1. He points out that the aims of a liberal education are as follows:

1. To discipline the mind so as to create a power for coördinate thought.
2. To impart a knowledge of facts.
3. To develop a power of expression in language or in action.
4. To discipline emotional sympathy so as to develop an esthetic taste.
5. To discipline the moral faculty.

The curriculum has a twofold purpose. First to assist the student in choosing a calling which will be congenial and suited to his ability, and secondly to develop equally all his faculties. While radically different in purpose from the arts course, the technical course should produce something of the same results. On the other hand, 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.

William Esty. At the same convention Professor Esty outlined several ways in which instruction can be made practical as well as scientific. The ideal education for the engineer is a literary and scientific course of a general nature, covering three or four years, followed by a

* An hour in this sense is one hour per week per academic year. This equals about 36 actual hours of lecture recitations, or quiz, or 72 actual hours in the drawing room, laboratory or shop.

special technical course extending from two to three additional years. The tendency to regard an engineering course as post-graduate professional work is increasing, as is evidenced by the increased number of graduates of humanistic colleges taking engineering studies. Professor Esty's rules for planning a course in electrical engineering are:

1 To teach thoroughly those things in college which are fundamental.

2 To devote little time to highly specialized subjects.

3. To introduce the student to those branches of knowledge which in his later life he can acquire only with increasing difficulty, if at all.

4. To endeavor to cultivate in him the hunger and thirst for more and deeper knowledge, so that he may remain a student throughout life.

H. W. Buck presented his views of the education of the electrical engineer from the standpoint of a technically trained practising engineer. 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 being familiar with machinery and its design, in order to be a worker in the broadest field. 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, then a college course with general subjects during the first year, followed by those general and theoretical subjects that have a direct bearing upon the practice of the electrical profession. This includes such studies as mathematics, mechanics, physics, chemistry, theoretical electricity and magnetism, and thermodynamics. This study should be supplemented by actual daily practical work with machinery operated by the principles covered by the theory studied, and demonstrating all the phenomena incident to the theory. Mr. Buck advocates practical apprenticeship work subsequent to the completion of the college course. In addition to the theory and practice involved in this training, other elements are necessary for the successful engineer. There are many qualities required in common with other professions; executive ability, business knowledge, presence of mind, ability to handle men, nerve, resourcefulness in handling machinery in times of emergency—all these are necessary for the successful engineer. These elements cannot be acquired in the study of theory and practice alone, for many men who have stood high in their college courses have afterward failed in the practice of their profession because of a lack of some or all of these qualities.

E. B. Raymond. In another paper at the Great Barrington convention Mr. Raymond proposed the dropping from technical courses of all subjects not of a technical nature, such as language, history, literature, and political economy. The time should be spent entirely upon a theoretical and practical course, which will produce broadminded men with intellect, strength, training, and purpose. To this end the professors should be men of force of character, as well as men of intellectual attainment, and the courses at college should be so arranged that recitation rooms and laboratories could be regarded by the students as we look upon our offices. One of the most essential qualifications of the successful engineer is that he shall be filled with the desire for continual study. After graduation is the time for him to get his knowledge of real detail, amplifying the general knowledge obtained in college by practical investigation.

The discussion on the above papers was even more extensive and interesting than that at Chicago, and indicated an increased interest on the part of practising engineers.

1903. ANNUAL CONVENTION, NIAGARA FALLS

At this convention a joint session with the Society for the Promotion of Engineering Education was held. Messrs. J. G. White, Bancroft Gherardi, L. A. Osborne, representing employers of technical graduates, and Professor Dugald C. Jackson presented papers The consensus of opinion expressed in these papers is that the personality of the technical graduate is of more importance than any information which he may have acquired.

J. G. White. The results of a successful education may be summarized as (*a*) the satisfaction which results from possession; (*b*) the ability to enjoy good society; (*c*) the practical use which may be made of the training; (*d*) the ability properly to know any subject, and (*e*) the higher rank which will be taken as a result of this training.

Technical education should produce *engineers*, not students. It should develop not dreamers, but workers, thoroughly competent in their spheres whether great or small. It is better for the world and for the man that he should be a high-class mechanic or artisan, with a good common-school education, than that he should be nominally an "engineer", having a smattering of many subjects. *The importance of thoroughness is supreme.*

The telephone engineer's work is an example of the severe requirements of engineering practice. A few years ago many of us would have supposed that the problems of the telephone engineer were those of a high-class artisan, but a modern telephone engineer must even know something of architecture, the strength of materials, and other factors entering into modern steel building construction, and be familiar with many other subjects not ordinarily supposed to come within the province of a telephone engineer. Other engineers should likewise have a general knowledge of the sciences and of the broad underlying principles of engineering, based upon a thorough mastery of elementary mathematics and supplemented by some study of languages, history, civics, and other studies of general educational value.

Bancroft Gherardi. Treating the subject from the standpoint of the telephone engineer, Mr. Gherardi lays down the general proposition that an engineer's qualifications are made up of two factors, personality and training. The training of a telephone engineer should not be essentially different from that of other electrical engineers, the training of any engineer properly consisting of such studies as will convince him of the necessity of getting facts, and teaching him the best method of doing so. Further, these studies should train in the interpretation of engineering data and in reasoning from them. Throughout his paper Mr. Gherardi emphasizes the necessity for relating theory and practice, suggesting that while fundamentals should be the most prominent, examples should be drawn from each branch of electrical engineering to which the fundamental principle may apply. In this way the value of the principle will be borne in upon the mind of the student. He will be helped to see theory and practice in the proper perspective, and will be aided in deciding upon the particular branch of engineering for which he is being fitted. The examples will also not be without some practical value in his early professional work. In regard to his experience with technical graduates, Mr. Gherardi states that the training they receive, notwithstanding its imperfections, is of great value to them and to those for whom they work.

L. A. Osborne impresses the facts that the large majority of young technical graduates are not fitted by temperament or training for pure engineering work, and that they regard it only as a stepping stone to business. At the same time the teachers of these men have proceeded on the assumption that they would be ultimately engaged in engineering. He therefore advocates the broadening of courses to the end that the whole body of engineers will enter upon their work with a fuller comprehension of its duties and opportunities. Mr. Osborne contends that shopwork should be taught with a view to training the student in the principles which underlie the tool organism of a shop. He should know more about the functions of tools, the principles of their design, and their relations to each other. While it is true that familiarity in these lines comes largely from experience, the author infers that the schools can have a share in providing it. Works-accounting, the problems of capital and labor, the law of contracts, and other such apparently non-engineering subjects should not be neglected in the engineering curriculum.

Dugald C. Jackson. Professor Jackson calls attention to the fact that since he brought up the subject in 1892, the sentiment regarding college men has entirely changed. These men have become influential in engineering practice. The business of the engineering colleges is to produce, not finished engineers, but young men with a great capacity for becoming engineers. The names attached to the subjects taught are not very important as the results produced by the teaching, namely, the effect produced upon the students, show. The ideal engineer is competent to conceive, organize, and direct extended industrial enterprises of broadly varied character. He must be a keen thinker with an extended knowledge of natural laws, and an instinctive capacity for reasoning from cause to effect. He must also know men and their affairs, business methods, and the affairs of the business world. The ideal course in electrical engineering should include the following underlying training.

1. That fuller training in the construction of the English language which is requisite to clear thinking and clear writing, preferably accompanied by an additional language for added strength.
2. The collateral art of expression in drawing.
3. Mathematics through an appropriate amount of calculus, including the integration and solution of equations involving derivatives, and instruction in the use of co-planar vectors, and perhaps quaternion quantities—all of which should be taught as applied logic with special emphasis laid on interpretating the meaning of equations.

4. The science of chemistry, soundly taught.

5. The science of physics soundly taught, with particular emphasis laid on the elementary mechanics.

6. Applied mechanics.

Mechanics—the philosophy of matter, force, and energy—is the backbone of the electrical engineer's college training.

He also outlined laboratory and practical courses, which should accompany the fundamentals. He deprecated the use of descriptive courses as having a tendency to neutralize the advantage resulting from instruction in fundamentals.

The work in electrical engineering should be divided into: applied electromagnetism, the theory and practice of alternating variable currents, applied electrochemistry, electrometallurgy, and electrical installations.

In analyzing the courses advertised in college catalogues Professor Jackson finds three varieties of instruction. In the first of these, electrical engineering is taught as an illustration of the beauties of nature, rather than of its great underlying laws. The instructors in these courses are out of touch with the industrial world. The second class of instruction is apparently intended to train inexperienced students to assume positions of responsibility and large remuneration. The third variety of instruction approximates the ideals laid out in the paper. In closing, Professor Jackson states that many of the greatest weaknesses in engineering courses are that the heads of colleges or universities do not understand what engineering truly stands for, and they often have no fair conception of the soundness of training that is required for its practice.

1903. September Meeting

Chas. F. Scott, in his inaugural address as president proposed that universities and technical schools with educational engineering departments should hold local meetings of the Institute for benefiting both instructors and students by keeping them in touch with recent developments and practice. It is argued that theoretical training in fundamental principles should predominate and that such Institute meetings will enable the student to keep in touch with actual things and give him a more adequate idea of the career for which he is preparing. It will supplement his theoretical training, making it definite and certain, so that he may properly assimilate the instruction he receives. It will show him that the electrical engineer needs much more than mere technical training, and it will tend to make his college work less abstract and more concrete and efficient.

1907. Annual Convention, Niagara Falls

Henry H. Norris. At this convention education was the subject of two papers; one by Professor H. H. Norris, the other by Professor V. Karapetoff. In Professor Norris' paper emphasis was laid upon the elements of personality in the technical students. The elements of success in technical training are:

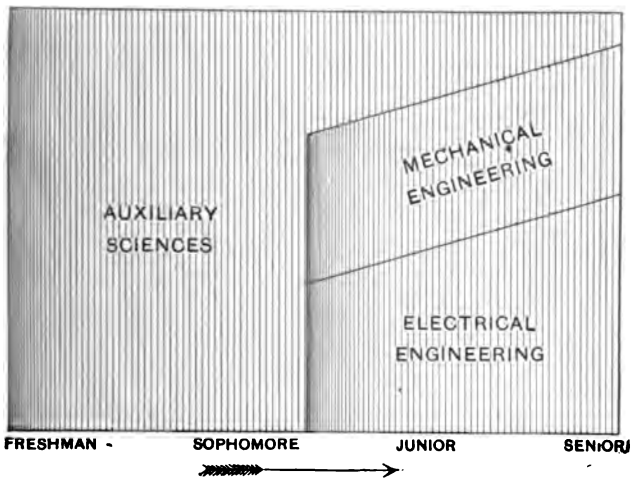
1. The attraction and retention of desirable students and the exclusion of those not qualified for technical work,

2. The selection of such studies as will stimulate and direct mental activity.

3. The conducting of all courses in such ways as will tend to bring out the desirable personal qualities in the students.

4. The recommendation to the students of those lines of engineerin practice for which they are best suited.

In developing the subject the author made use of a magnetic analogy of a technical training. The mind of the student was compared to a piece of magnetic material which possesses the ability to be magnetized on account of the inherent magnetism of its molecules. A piece of iron or steel is magnetized when its intrinsic qualities are subjected to a direct magnetomotive force. In a similar manner the young men entering the technical school possess certain elements of personality. The function of the instruction is to supply the directive force necessary to bring out the student's latent qualities. The student gets little that



is new from his college course, and if the attempt is made to impart to him more information than is necessary to stimulate him to his best endeavors, mental saturation results. The writer traces the history of the technical school, and refers in some detail to that of Sibley College, which with the Massachusetts Institute of Technology was a pioneer in electrical engineering instruction. The present curriculum of Sibley College was outlined in order to permit it to be compared with the ideals laid down. In order to indicate the lines of work taken up by technical graduates an analysis of the present occupations of the numbers of graduates of Sibley College was given.

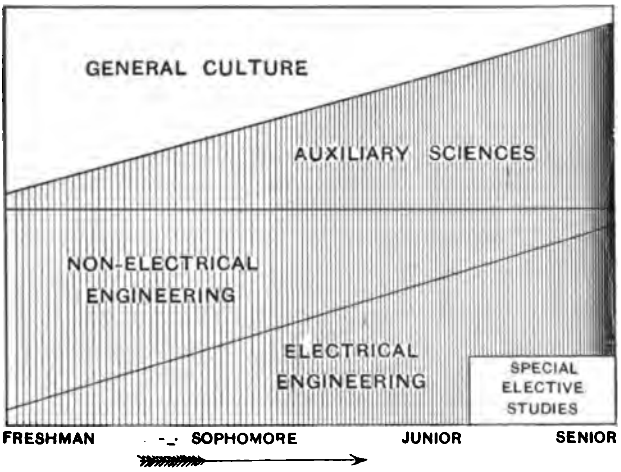
Vladimir Karapetoff. In his paper "On the Concentric Method of Teaching Electrical Engineering" Professor Karapetoff outlines a four-year college course different from the usual courses in two respects:

1. The course begins with the practical descriptive side of engineering and gradually leads into the theory, contrary to the present system, which begins with the theory.

2. Each year is made as far as possible self-contained, so that the student's horizon is gradually "concentrically" widened, and he is prepared for lower practical positions after the very first year in the college.

Moreover, according to this method, the student does not need to select a particular branch of engineering the first, or even the second year. In the first year he gets a "cyclopedia" of electrical, mechanical, civil, and mining engineering, and is given a chance to judge for himself which branch he likes the best. In the second year he is again given an opportunity to select between the mechanical and the electrical engineering. In the third year he gets straight electrical engineering; and in the fourth year specializes in the mathematical and physical theory of his profession. He also chooses a few elective branches, such as electric railways, telephony, power transmission, design, etc.

The advantages claimed for the above arrangement of the courses are as follows:



1. The student selects his profession after having had an outline course in it, in parallel with a few other allied specialties.

2. The method of beginning with the practical side, in other words with the ultimate results, is more psychological than beginning with abstract auxiliary sciences.

3. The interest and the professional feelings in the student are early aroused.

4. He can spend his vacations more profitably, having had engineering courses from the start; he can also be interested in technical literature and societies earlier than is possible with the present method.

5. A possibility is created for producing "learned artizans" who have taken one or two of the early years, and may then be useful in practice as assistants, or can do independent work in newly opened parts of the country, etc.

6. The theory, being built on the known facts of experience, will be less abstract, and more in unity with the requirements of practice.

A paper presented at a special meeting of the American Institute of Electrical Engineers, New York, January 24, 1908.

ELECTRICAL ENGINEERING EDUCATION

BY CHARLES P. STEINMETZ

When in the following I dwell more on those features of our electrical engineering education which appear to me unsatisfactory, it is not that I overlook the many good points, but rather that a criticism of the few defects appears to me more important, for the purpose of urging their elimination.

In general, the conditions for a good electrical engineering education in the United States are far more favorable than anywhere else; for an electrical engineering industry developed to a higher degree and to a greater magnitude than in any other country offers a very large field of application to the graduate engineer, thus supplying an incentive to enter this profession. Unlike other countries, where some opposition to the college-trained man, as unpractical, still lingers, the electrical industries here prefer, and in many instances demand, a technical college training for their engineering staffs. There is a tendency now to demand this training even for administrative and commercial positions. This leads to a close coöperation between the electrical industry and the engineering college. The leaders of the industry take a close and active interest in technical educational work, while teachers of engineering consider it as their foremost duty closely to follow and keep informed of the advances of the electrical industries, sometimes even are actively engaged in industrial work; and as early as possible the students are introduced to the industry, by visits to factories, inspection trips etc., which become more and more an important part of the college education. This is as it should be, and probably constitutes the strongest features of American engineering education.

While many, especially smaller colleges, are not financially strong, in general the means available to the American college of engineering are far superior to those abroad, and especially in erecting engineering buildings, laboratories, etc., much has been done.

The great defect of the engineering college is the insufficient remuneration of the teaching staff: the salaries paid are far below those which the same class of men command in industrial work, and as a result the college cannot compete with the industry for its men, but most of the very best men are out of reach for the colleges. The teaching forces of the colleges therefore consist of: 1. A few of the very best men, who are specially interested in educational work to such an extent that they are willing to sacrifice financial returns for it. These men have made the engineering college what it is, but even many of these men are ultimately forced by considerations of family, etc., to leave college work and enter industrial employment. 2. Many younger men interested in teaching, enter college work to give it a trial. Some of these remain, but many return to industrial work, when they are forced to realize the small prospect of financial return offered by the college. 3. First-class men who devote a part of their time to the college and a part to industrial work, usually consulting engineering. This arrangement is probably the best for the college, handicapped as it is by the policy of salaries which may have appeared sufficient in branches in which no industry competes, but which are suicidal in the engineering department. Still it would be far preferable if the colleges could get the benefit of the whole time and the undivided interest of these men.

It appears to me, therefore, that a vast improvement could be made in electrical engineering education if a large part of the sums which now are devoted to marble engineering buildings and fancy laboratory equipments could be devoted to offer such salaries as to make available to the colleges the undivided time and interest of the best men in the field. The name of the donor may just as well be perpetuated by the professorship which he endows, as by the pile of marble which he erects for the college. After all, engineering buildings and college laboratories are of very secondary importance compared with the qualifications of the teacher and his assistants.

To the subjects taught and the methods of teaching very grave objections may be made. The glaring fault of the college curriculum is that quantity and not quality seems to be the object sought: the amount of instruction crowded into a four years' course is far beyond that which even the better kind of student can possibly digest. Memorizing details largely takes the place of understanding principles, with the result that a year after graduation much of the matter which had been taught has passed out of the memory of the student, and even examinations given to the senior class on subjects taught during the freshman and sophomore years, reveal conditions which are startling and rather condemnatory to the present methods of teaching.

It stands to reason that with the limited time at his disposal, it is inadvisable for a student to waste time on anything which he forgets in a year or two; only that which it is necessary to know should be taught, and then it should be taught so that at least the better student understands it so thoroughly as never to forget it. That is to say, far better results would be obtained if half or more of the mass of details which the college now attempts to teach, were dropped; if there were taught only the most important subjects—the fundamental principles and their applications—in short, all that is vitally necessary to an intelligent understanding of engineering, but this taught thoroughly, so as not to be forgotten. This, however, requires a far higher grade of teachers than are needed for the mere memorizing of text-book matters, reciting them, at the end of the term passing an examination on the subject and then dropping it. The salaries offered by the colleges are not such as to attract such men. When the student enters college he is not receptive to an intelligent understanding, for after a four years' dose in the high school of the same vicious method of memorizing a large mass of half and even less understood matters, the student finds it far easier to memorize the contents of his text-books than to use his intelligence to understand the subject-matter. After graduation, years of practice do for the better class of students what the college should have done—teach them to understand things. It is, however, significant that even now young graduates of foreign universities, in spite of the inferior facilities afforded abroad, do some of the most important electrical development work of this country. Men who never had a college education rise ahead of college graduates. This would be impossible if our college training gave what it should, an intelligent understanding of electrical engineering subjects.

The cause of the fault is perhaps the same that leads to the erection of engineering buildings and laboratories while underpaying the teaching staff: the competition among the colleges. To the father who looks up a college for his boy, marble engineering buildings and fancy laboratories are impressive, and so is an extensive curriculum; the result is a rapid increase in the number of students; but it is not to the benefit of the student, since the faster a subject is learned the faster also it is forgotten, and to become and remain thoroughly familiar with a subject, it is necessary to keep up the study of it for some years. While it is a good feature to insure application of the student by term examinations, etc., this becomes harmful if it leads to dropping the subject at the end of the term. The least that can be expected from the college is that at the time of graduation the student still knows all that he has been taught during his college years. To accomplish this it is necessary to keep up the study of every subject to the end of the college course. This is not the case at present.

The different colleges vary between the school teaching the trade of electrician, and that attempting to give an intelligent electrical engineering education. At the one extreme is the college which dropped from its curriculum everything not required in electrical engineering. Such a school covers a large ground in electrical engineering, may even consider shortening the course to three years. The graduate of such a course is a full-fledged electrical engineer, capable to ply his trade, just as a plumber or brick layer when graduating from his apprentice years, and just as helpless and useless when any occasion arises requiring general knowledge to enable him to understand matters beyond his trade. The unavoidable result of such training is, that when with the development of the industry subjects become of importance which were not considered as pertaining to the trade of electrical engineering during his college years, his usefulness is impaired, younger men rise above him, and he cannot hope to rise beyond a subordinate position. Fortunately, the better technical colleges realize that the first requirement of an electrical engineer is a thorough general education, and begin to realize that for this purpose it is not sufficient to require general subjects for college entrance and relegate their study to the high school: for even if the average high school were what it should be and not what it actually is, much of the general knowledge required by an educated man cannot be taught in the high school, since during the high-school years the intelligence of the boy is not sufficiently ripened for its grasp, and a review in the college is necessary.

However, even if an attempt is made to teach or to review general subjects, the work is not carried sufficiently far. Mechanical engineering, physics, chemistry, and some civil engineering subjects are recognized as legitimate subjects of teaching in the electrical engineering course in many colleges, together with literature, some history etc.; but physiography, physical geography, meteorology, mineralogy, astronomy etc., are also of importance in a general engineering education. The failure to recognize this may sometime be a severe handicap to the electrical engineer, and that in the not very far future, judging from the present trend of development. In this direction the student, as well as his parents, are frequently antagonistic, and cannot see why subjects should be studied, which to their limited horizon appear unnecessary.

The instruction given in those branches of science, a knowledge of which is required by the electrical engineer, but to which only a limited time can be devoted, as chemistry, civil engineering etc., frequently is very unsatisfactory, being unsuited to the requirements of the electrical engineer, and, as a result, of very little if any value to him. A general knowledge of these branches is required, so as to familiarize the electrical engineer with the general problems, methods, and purposes of the science; to enable him to understand subjects dealing with these sciences. The ability actively to practise the science is not required. To illustrate in the case of chemistry: the electrical engineer should have a knowledge of the laws of chemistry, a familiarity with the elements and their compounds, and a general knowledge of the methods of analysis and synthesis. Such a course must, therefore, necessarily be largely descriptive, and the experimental work largely illustrative. The same course is frequently given to the electrical engineer as to the first few terms of the chemistry student: general inorganic chemistry of the most important elements, and qualitative analysis. While a first-class beginning of a course of chemistry, such a course leaves the engineer with a knowledge altogether too fragmentary to be of benefit to him, and the time spent in mastering the mechanism and the details of qualitative analysis is largely wasted, since the electrical engineer will probably never be called upon to make an analysis. If he attempted to do so he would probably fail. The beginning of a chemist's training is not suited to the chemical training of the electrical engineer, and the same applies to all other sciences to which a limited time is devoted in the electrical engineering curriculum. To give a general view and working knowledge to the electrical engineer of such an allied branch of science, theoretical discussions, especially mathematical, are usually very little needed and therefore undesirable. A characteristic case of spoiling a science to the student by mathematics is that of astronomy. Astronomy is one of the most interesting and fascinating of subjects. But where taught as a part of the general educational program, it frequently is all mathematics, and so hopelessly dry and repellent. It should be given descriptively, for in a short course on astronomy it is just as ridiculous to delve deeply into mathematics as it would be to start the teaching of geography with a course in spherical trigonometry. I believe that in the teaching of allied sciences our colleges and schools are still greatly inferior to those abroad; the result is very marked in the product of the colleges, in the inferiority of the general education possessed by our graduates.

It goes without saying that in all teaching the strongest endeavor should be made to correlate the different subjects, to show the students the close relations which exist between all the branches of science, no matter how different they appear at first sight; and to interest him by bringing home to him the practical importance of what otherwise would appear dry theory. For instance, by using in the teaching of mathematics, problems taken from engineering; to have him handle and operate machines before proceeding to their theoretical investigation; then to derive the constants of the theoretical investigation from experimental tests of the apparatus; and from these predetermine the performance of the apparatus under different normal and abnormal conditions and experimentally verify it.

In conclusion, the main defects in the present electrical engineering training in some of our colleges appear to me as follows:

1. The insufficient remuneration of the teachers, which makes most of the best men unavailable for educational purposes and is, therefore, largely responsible for the other defects.

2. The competition between colleges, which leads to a curri-

culum marked more by the quantity of the subjects taught than by the thoroughness of the teaching. The graduates are sent out with a mass of half understood and undigested subjects, quickly forgotten, and deficient in understanding of the fundamental principles and in the ability to think.

3. The tendency of some colleges to teach the trade of electrical engineering rather than educate intelligent and resourceful electrical engineers.

4. The unsatisfactory state of the teaching of allied sciences, which gives instead of general view and understanding of the science, a fragmentary knowledge of some details.

DISCUSSION ON "THE EDUCATION OF THE ELECTRICAL ENGINEER." NEW YORK, JANUARY 24, 1908.

Charles F. Scott: Since preparing this short paper which I intend to present this evening, I have taken part in a symposium on "The Teaching of Mathematics to Engineeers" at a joint meeting of the Chicago Section of the American Mathematical Society and the Mechanical Section of the American Association for the Advancement of Science. My contribution seems to me so pertinent to the educational questions now under consideration that I shall present it here.

Mathematics, from the standpoint of the engineer, is a means, not an end. It is an instrument or tool by which he may determine the value and relations of forces and materials. The usefulness of tools depends upon the sort of work which is to be done, upon the kinds of tools which are available, and upon the skill of the man who uses them. We may inquire, therefore, what are the uses to which the engineer may apply mathematics? What kind of mathematics does he need? And what skill should he possess in their use?

First, then, what work is to be done by the young men who are now taking engineering courses? A few—and only a few—will be original investigators or designers who will need mathematics as an instrument of research. A considerable number will regularly employ elementary mathematics in more or less routine calculations. Many will have little use for mathematics, as engineering courses are recognized as affording excellent training for various business, executive, and other non-technical positions, particularly in connection with manufacturing and operating companies. It has been said by the vice-president of a large electric manufacturing company that not over 10 per cent. of the technical graduates employed by that company are fitted by temperament or by education to take up with success the work of pure engineering. A recent classification of the graduates of Sibley College, Cornell University, shows that about 50 per cent. are in occupations which require no advanced mathematics, and it is probable that many of the 36 per cent. classed as mechanical and electrical engineers seldom go beyond the rules of arithmetic. Hence a goodly proportion of engineering graduates do not need to be mathematical experts. Their mathematical studies should not aim to produce experts, but should have as a principal object the mathematical training which is a most efficient kind of training in an engineering course. On the other hand, the engineers who will have practical use for the higher mathematics will find their ability as engineers is in a large measure determined by their ability as mathematicians.

Secondly, what kinds of mathematics does the engineer need? This is closely related to the class of work he is to do. In general, a great deal of engineering work is done with much less use of higher mathematics than most professors probably imagine, and furthermore, it may be remarked, with much less than could profitably be employed. Engineers are apt to use ordinarily the mathematical methods with which they are most familiar and which will bring the result with the least effort. One man employs calculus, another draws a diagram, another writes out formulas, while still another gets his results by mental arithmetic. The object is to get the result. The fundamental idea that mathematics is something for the engineer to use finds many illustrative analogies in ordinary tools.

Adaption is the first requisite; tools should be suited to the work to be done. An expensive machine-tool with its refined adjustments is quite unnecessary for executing a piece of work which can be done with sufficient accuracy by a few minutes' application of a file. In every-day work an ordinary calculating slide-rule is infinitely better than a table of seven-place logarithms. On the other hand, it is particularly wasteful to attempt to execute a difficult and intricate piece of work with inadequate tools. But more important than the tool is the skill of the man who uses it. A skilful workman can accomplish results with a few simple tools which another cannot get with the most elaborate special equipment.

Thirdly, therefore, skill in the use of mathematics is the really essential thing. A judicious use of arithmetic with a little algebra or a simple diagram often leads to more satisfactory results than others obtain through elaborate processes involving lengthy equations and complicated operations. In the latter, errors are liable to occur: the common-sense import of the problem is apt to be overlooked; assumptions may be made to facilitate calculations which are physically unwarranted, as one loses sight of the physical problem in the intricacy of the mathematical solution. Abstract mathematical studies, if pursued as a kind of intellectual callisthenics, may produce a pure mathematician, but they may unfit a man for practical engineering. A mathematician is not necessarily an engineer, nor is an elocutionist necessarily a good lecturer, nor a tool expert a successful manufacturer.

Mathematics is used in engineering to express the quantitative relations of natural phenomena. The mathematician delights in the relations; he divorces them from the phenomena and gives them abstract expression. But the engineer is concerned with the natural phenomena: he demands the physical conception; the medium of expressing these relations is of secondary consequence.

The mathematician evolves the equation for a parabola and finds a convenient illustration in the law of projectiles. The engineer finds that a physical result follows from the application of certain forces, and uses the formula merely as a convenient method of expressing the law. The analogue in the case of mechanical tools is found by regarding a set of drawing instruments or a transit or a lathe, as something intelligently designed, properly proportioned, accurately made, and finely finished, the merit of which lies in their own inherent excellence, or, on the other hand, by considering them as tools adapted for doing a certain range and character of work with a sufficient degree of accuracy and at low cost.

A manual training school gives familiarity with mechanical tools, and mathematical study gives familiarity with intellectual tools. In working with the manual tool, the boy uses it for making something; by making something, he learns the principle on which it operates and the way to use it. If the thing made is something useful, it awakens a keener interest than perhaps would some fancy device. Likewise training of engineers in mathematics should be by doing something, by the solving of problems, by dealing with real rather than abstract conditions. Let this training be obtained while applying mathematics to its normal and legitimate purpose as an auxiliary to the study of other branches.

In the teaching of mathematics for its own sake stress is apt to be laid upon the processes of deriving results rather than the real meaning of the results themselves. An engineer who uses logarithms has no more concern regarding their derivation than the ordinary user of the dictionary for finding the pronunciation of words has in their etymological derivation. The ability to reproduce demonstrations in higher mathematics from memory with the book shut is often not as important as it is to understand them with the book open. In general, an engineer who has occasion to use higher mathematics, will not be interested in evolving difficult equations, nor will he appeal to his memory; but with text-book or reference before him he will seek the things he wants to use. He should know where to find them and how to use them.

In emphasizing what a skilled mechanic can make with very ordinary tools, or the true engineer can accomplish with the parallelogram of forces and the rule of three, there is no intention of discrediting the value of fine equipments both mechanical and mathematical if there be the ability to use them.

Possibly the practical utility of mathematics may appear to be urged too strongly, particularly as the writer really believes in thorough mathematical training; but he has seen so many cases in which mathematical instruction has never been digested and assimilated, so many simple mental processes confused by unnecessary mathematical complications, so many men satisfied with results which are absurd because of some mathematical equations, sometimes quite unnecessary—that a common-sense perspective view of ordinary things seems to need emphasizing. He recalls the new insight into mathematics which came through the study of analytic mechanics under Professor S. W. Robinson at the Ohio State University, and problems in mechanics under Dr. Fabian Franklin at Johns Hopkins University, that he feels there is little danger in over-emphasizing the importance of concrete training in mathematical study.

The practical questions which the discussion of this subject presents are these:

1. What mathematical subject-matter should be covered?
2. How should it be taught?

The first difficulty is that there is not, and cannot be, a differentiation in technical education which is at all comparable with the wide range of occupations into which graduates will enter. We may assume, therefore, that we are considering the case of the average engineering student, taking for granted that options may be used by the best students to enable them to take up the more advanced and difficult mathematics. Obviously, the student should have enough mathematics to enable him to demonstrate the important engineering laws and formulas, and to read intelligently mathematically written engineering literature. While only the relatively simple mathematics is commonly used by engineers, yet the ability to handle new problems with confidence requires a thorough understanding, and appreciation of the significance of the mathematical and physical basis of the laws and phenomena he is to use. A man who is a thorough mathematician and knows how to apply his knowledge has a great advantage over the pure mathematician or the man without mathematical training. The better knowledge one has of the complex, the more certainty he has in applying the simple. A student should understand something of the power of the advanced mathematics and the field of their efficient application. Although he may not be expert in using them himself, he will know when to call for a mathematical expert.

An engineer of fairly wide experience remarked a short time ago:

> The ordinary engineer does not use higher mathematics because he doesn't know how. He does not have the proper conception of the fundamental principles of the calculus because the subject has been taught by men whose ideals are those of pure mathematics.

If mathematics is something for engineers to use, let their use be taught to engineering students. After the fundamentals are learned, the students should attack the engineering problem at once and bring in mathematics as a means of solving it. Mathematics is often advocated for developing the reasoning powers and the ability to reason from cause to effect; there is danger, however, that mathematical machinery may make the mere process obscure the cause and the effect. Let cause and effect be foremost, with the process secondary or auxiliary to them. The way mathematics is brought to bear on some engineering problems reminds one of the story of the old lady who greatly admired her preacher because he could take a simple text and make it so very complicated.

Old traditions have not wholly disappeared; the fear of degrading the pure science of mathematics by applying it to useful things still lingers—in influence, if not in precept. We must go further and adapt mathematics to engineering, not only in subject-matter, but in method. A mathematical teacher with no patience for anything except mathematics will probably teach a kind of mathematics which has no connection with anything except mathematics. Engineering mathematics may be better taught as a part of engineering by an engineer, than as a part of mathematics by a pure mathematician. The maker of levels and transits who is expert in the construction of the instruments and an enthusiast over the accuracy of the surfaces, the excellence of the bearings, the near approach to perfection in the graduation, and the general refinement and beauty of workmanship, may make a good instructor on instruments, but a poor teacher of civil engineering.

After all, it is not so much abstract courses as it is men with which we have to do; it is not mere knowledge of facts or facility in mathematical manipulation, but it is training. The young man is to be developed; his native individuality is to be the basis; he is to increase not only his knowledge but his powers and the ability to use them. It is not mathematical skill so much as a mathematical sense, or mathematical common-sense, which is wanted. With pure mathematics as a science we have no quarrel—and little affiliation.

We are concerned with applied mathematics. The ability to state a problem; to recognize the elements which enter into it; to see the whole problem without overlooking some important factor; to use good judgment as to the reliability or accuracy of the data or measurements which are involved; and, on the other hand, the ability to interpret the result; to recognize its physical significance; to get a common-sense perspective view of its meaning and the consequences which may follow; to note the bearing of the various data upon the final result; to determine what changes in original conditions may change a bad result into one which is practical and efficient—such abilities as these are of a higher order than the ability to take a stated problem and work out the answer. It may be urged that all this is not strictly mathematics. But it is just this sort of judgment and insight which makes mathematics really useful, and without them there is danger that they may be neither safe nor sane.

If you ask men who use engineering graduates what qualities they should possess, you will find that special prominence is "common-sense" and "the ability to do things." In mathematical training it is quality rather than quantity which is of first consequence. Mathematical training should develop a faculty for systematic and logical reasoning, thus furnishing a general method as well as a specific means of getting results.

The trend in education is to a closer relation to the affairs of life. Science and applied science, scientific and engineering laboratories are overcoming old ideas and prejudices. Modern engineering development brings its transforming influence to bear upon education as well as the utilities of modern life. The engineering school has had a phenomenal growth within the lifetime of the recent graduate—a growth in ideals and methods as well as in students and equipment. It has raised and agitated broad questions as to what constitutes efficient education for producing effective men. It has aimed to combine not only the abstract with the concrete, the lecture room with the laboratory and the scientific experiment with the practical test; but it has sought by various means to bring the work of the school into close relation with active professional and commercial practice. It has a definiteness of aim and purpose which other educational courses are apt to lack. It sets out to produce men who can deal with forces and materials according to scientific principles. It develops men whose contact with physical facts and natural laws at first hand and whose ability to reason logically fit them for dealing with new problems. The training which fits men for handling engineering problems is the kind that is needed for dealing with the organizing and directing of men. The sphere of the engineer is one the scope of which will continue to increase as engineering education and training produce men whose contact with natural phenomena gives them an inherent respect for facts as their premises, who are able to think straight to logical and commonsense conclusions, who have an equipment of technical knowledge and who can produce results.

In discussing the teaching of mathematics to engineers, we should emphasize not the mathematics nor the engineers, but the teaching. Aside from the imparting of knowledge and technical ability, the teaching of mathematics gives opportunity for training in the use of logical methods and in the drawing of intelligent conclusions from unorganized data which will make efficient men, whether they follow pure engineering or semi-technical or business pursuits. Such teaching does not come from the text-book; it must be personal—it comes from the teacher. He must be in sympathy with engineering work and have a just appreciation of its problems and its methods. He must be imbued with the spirit and the ideas of the engineer.

Chas. P. Steinmetz: I agree with Mr. Scott in the relation of mathematics to engineering. I agree with him also that mathematics is a tool, the most important and useful tool of the engineer; but it is useful and valuable only as long as it is a tool, and ceases to be useful as soon as it goes beyond a tool and becomes a purpose. Mathematics becomes not only useless but positively dangerous as soon as the user does not fully and clearly see the physical meaning of every mathematical step he takes, or fully appreciates the physical meaning of every step when reading through a mathematical derivation of a result. As soon as one understands the physical meaning of every step, one can, as a rule, greatly simplify the mathematics by skipping complex mathematical reasonings by a short cut based on common-sense. For instance, instead of carrying the calculations through with the positive and negative signs of a square root, one can frequently say: for physical reasons, the sign must be positive, and drop the negative, or inversely. Mathematics is merely a shorthand method of recording physical intuition and physical reasoning, but it should not be a formalism leading from nowhere to nowhere, as it is likely to be made by one who does not realize its purpose as a tool.

L. A. Osborne: One may very easily assume a dogmatic attitude in giving expression to opinions upon the subjects treated of in to-night's papers. That is a state into which we are very prone to fall, and in the interest of real progress it is important that we should avoid it.

As engineers we are quite content to accept criticism from the layman of the structures which we build and plan, but when he attempts to tell us how to fashion our productions to accomplish the result which he requires, then we rise up and object. I feel this way about commenting on engineering education.

Some years ago I was persuaded to express my views upon this subject, which I did before this body, and I made up my mind never to venture upon such slippery ground again. The cries which went up from some of my academic friends led me to this renunciation, although there was an occasional friendly word which relieved the situation of utter hopelessness. That was several years ago. Now there is some satisfaction in knowing that some of the views expressed in my paper have since been adopted, and in a number of cases I have been accorded more credit than I deserved as the originator of some of the ideas there advanced.

I do not believe in telling the teachers how to do their work; I think we should better state what the finished work lacks. I am a product of the engineering educational methods in vogue fifteen or twenty years ago, and have long been what might be termed a purchasing agent for the consumer of the products which the schools turn out. I have thus been able to note certain tendencies, the resultant effects of which have left on my mind a sort of composite picture of the technical graduate as he has passed before my vision for the last ten years. While individuals may have qualities which set them apart from the crowd, still the average impress of the whole is that which produces the composite effect, the one which remains with me. Without presuming to point out how the quality can be improved, I recount here certain impressions which remain from my experience:

First, that 50 per cent. of the technical graduates that present themselves to be employed might better never have undertaken their profession; that at least that proportion of those with whom I have come in contact have apparently chosen an engineering profession more in the hope of the emoluments and not from any real interest in or love for the work.

How the real engineers can be detected in the first instance is a matter beyond me; but it is quite certain that a process of elimination which will put into the engineering classes men earnestly loving their chosen work, would not only make those men better fitted but would be a greater inspiration to the profession and a greater credit to their colleges.

Secondly, that of all those who remain, who may be termed good promising timber, the chief fault that I have to find with them, is that they are generally unable to grasp abstractions, that they are unable to generalize. Inasmuch as engineering *per se* is a profession dealing with specific problems, the tendency which follows application to its studies leaves the individual less able to treat with generalities. This is a question, therefore, of injecting into the courses something which will stimulate the powers of generalization which, broadly speaking, is more general culture.

Professor James has written very entertainingly in a recent magazine issue on the subject, " Of what use is a college education ", and the answer there given is the answer to apply here, but perhaps in a more restricted sense. Professor James contends that a person having the advantage of a collegiate training is better able to discriminate between the good and the bad in mankind. To the engineer, his training should give him that fine degree of discrimination which enables him to know what is good and bad in engineering, and inasmuch as engineering has become so important an adjunct to our everyday lives, the engineer should likewise have the discrimination to enable him to judge between the good and bad in mankind itself. We want men who know good jobs when they see them, whether the job is man-made or made by nature in the form of man himself. Engineers to-day are too self-centered; too bound up in the details of their profession. They are not as a rule men of the world but are men in the world with a too narrow perspective, largely due to the fact that their early training did not stimulate them in the right direction.

H. E. Clifford: There is at this time a very general agreement as to the advantages of a broad training for electrical engineering students, a training involving both breadth and depth. We do not want a training that is so broad as to be superficial. We want a training which is well proportioned as to breadth and depth. It is interesting, I think, to note that a basis of science and cultural studies for engineering education was specifically stated by President Rogers, the founder of the Institute of Technology, in his application for the charter for that institution, and I distinctly recall the very strong emphasis which General Walker, during his presidential career with us, laid on these particular foundation stones of engineering training. There is, however, one danger, as it appears to me in this general agreement as to breadth of training, and that is the danger of the tendency to standardize education. It seems to me it would be a most serious drawback should this Institute or any body of men attempt to standardize educational methods. Education is not as yet more than an art, it is not an exact science; and standardization, while it may do for apparatus, certainly should not be applied to education.

The personal element has been emphasized in Dr. Steinmetz's paper. I think that is one of the highly important points to consider. A poor system may be made effective by a good teacher, and a good system can be ruined by a poor teacher. It is, after all, the personality of the teacher that accomplishes results. I may mention in this connection what has always appealed to me as a branch of research, as truly important as the research on inanimate things, namely, the research which the teacher certainly carries on in his investigation of a problem in teaching, as distinguished from a problem, it may be, in chemical or engineering investigation. There are many teachers, as there are many so-called research men, who are inadequately prepared for their work, who can carry out their teaching as research only under direction; in other words, they merely work along suggested lines but are not properly research teachers; but I do believe that research in teaching is an important branch of scientific investigation. After all, education has for its primary object the training of men to think straight, to think logically; and the particular type of education, whether it be civil engineering, or electrical engineering, or chemical engineering, is merely a medium for bringing that thing about. Teaching of men to think logically can be frequently, and is undoubtedly frequently accomplished by training which is absolutely non-engineering in character. I think that is the reason why very often college men without any technical training whatsoever handle the larger problems of engineering more successfully and satisfactorily than some of our men highly trained from a technical point of view. This teaching of men to think straight, to think from cause to effect, must be carried out both in the class room and in the laboratory. No amount of training will help some men. Genius is not developed in a technical school unless there be some spark to begin with, and men without capacity, I believe, should be eliminated early.

I believe that many of our educational institutions are inclined to be too lenient in cutting out men who have no place whatever in engineering education, and I believe that a distinct step forward would be made if we should attempt to eliminate from the student body early in the course those men who convince us absolutely of their inability for the line of work which they have chosen. By eliminating these men, we should then have a class made up of men of exceptional ability and men of average ability. I would go further and suggest the segregation of the men of exceptional ability and the men of merely ordinary ability. I do not mean by this that I would put in the exceptional class the so-called—if I may use the college term—"greasy grind" type of man; but I mean the man who shows he has a broad outlook, keen intellect, real power—not the man who has intellectual facility which is quite apart from intellectual power. You may say, how are you going to tell such men? I believe that a good teacher can, to a great degree, discriminate between a man of merely ordinary ability, and a man of exceptional power; and I believe if this system were adopted that the results in producing men of the higher class of engineers would be very much superior to what exists to-day where men of moderate ability and men of superior ability are kept together and carried along in precisely the same way through a particular system of training. This would lead, also, I believe, to graduate work, a most important influence, and one which the technical schools have not begun to build up to the extent the importance of the subject demands.

Dr. Steinmetz also speaks of the importance of securing teachers from the open market. I believe that is also a very important point. The personal element is, after all, of paramount importance in teaching; and it seems to me absolutely essential that men should be secured and remuneration given which will enable these men to devote their time wholly to the problems of education. I do not mean that they are not to keep in contact with engineering progress; but there is great danger that a man who is trying to ride two horses will fall between the two. Teachers should keep in contact with engineering progress, but they should also devote their main interests to the educational side.

In regard to the matter of contact with engineering, some three or four years ago I gave considerable thought to this particular point, and it seemed to me it would be a very helpful thing if the interest, the knowledge, the breadth of view of consulting engineers could be brought into contact with the instructing staff of an engineering department. I suggested at that time to the authorities of the Institute of Technology the appointment of a committee of consulting engineers, and after due deliberation that committee was appointed. I believe that is going to be extremely helpful to us in bringing into the department the ability of men—just such men as Dr. Steinmetz refers to, men of force, men of standing in the engineering world, but who have the interest of the industrial rather than the teaching side of the subject first at heart.

In regard to thinking straight, I believe, as applied to the laboratory system, that every laboratory experiment should be made so far as possible a distinct engineering problem. It seems to me that the satisfaction which the students of to-day show in the *mere performance* of laboratory experiments is a very serious menace to the success of our laboratory system. Along these lines I suggested some three or four years ago a scheme of having every student in his laboratory work present a formal preliminary report of the scope of his investigation, the instruments needed, the particular scheme of operations, the results to be accomplished and their significance in the performance of the piece of apparatus being studied. This report is examined by some member of the instructing staff in consultation with the student before the work in the laboratory is performed, thus giving the opportunity for emphasizing fundamental principles and the advantage of personal contact of student with instructor. That is the system we are using at the Institute of Technology to-day and we find that it works infinitely better than the ordinary system of the mere perfunctory performance of laboratory experiments. There is one other point, and that is we must do something, I believe, to prevent undue collaboration in the student body. It is now very difficult to have a question concerning laboratory work take on even a semblance of newness after the work has been gone through with by a few sets of men.

A most important thing is to reduce the number of subjects taught in the curriculum. I heartily second what Dr. Steinmetz suggests on this point; and he has also suggested the difficulty in the institutions learning to do it themselves. Each institution fears if it reduces its curriculum it will be thought to be narrowing its training, instead of which it is broadening its training. There is too much fear that we may graduate a student who will meet something in his career outside of the institution, of which he has not heard or which will seem new to him. We must eliminate that feeling. Then too there is too much of the picture-book course. There are too many problems which involve merely the substitution of definite constants in definite formulas and do not require thought on the part of the students solving them.

If the function of this Institute is to advance engineering, and I believe it is, I think there is no better thing it can do than to study the engineering training in our colleges. I do not mean to study the engineering situation as ordinary men would study it, a mere cursory examination, the interviewing of a few instructors—they have as limited view points oftentimes as other people—but I believe this American Institute of Electrical Engineers might very well make a thoroughgoing investigation of our present methods of education, and I believe if they do that and then will make recommendations for the benefit of the technical schools, that will be something of even greater benefit than the standardizing of apparatus, or the preparing of a code of ethics or a code of engineering honor, and the influence of such an investigation will start on a more fundamental plane in the improving of engineering in this country.

F. B. Crocker: I agree with many of the remarks that have been made, including those of Professor Clifford and the points in Dr. Steinmetz's paper, also many of those in the paper by Mr. Scott. I must, however, take exception to one statement Mr. Scott makes in regard to the so-called concentric method. He says:

This system clashes with time-honored educational ideas, but it presents arguments which are so rational that the existing method must assume the defensive.

I think that any radically new idea must always assume the defensive, and personally I think the older method could defend itself if necessary.

The proposed method in which the descriptive, the general, and the pictorial, precede the analytical, has several objectionable features. Even assuming that it is ideal as an abstract proposition, it has certainly practical educational difficulties which are fatal. It appeals to the mind, I think, because it is attractive to the student, and therefore to one who is considering the case of the student; but the result would be to make every one an electrical engineer. Mr. Osborne tells us that 50 per cent. of those who graduate should never have entered the institution. How many more enter the institution and fail to graduate? If 50 per cent. of those who graduated should never have done so, it is fair to say that 75 per cent. of those who enter the institution should never have entered. The proposed method would graduate almost all who entered, 75 per cent. of whom should not do so. Another practical objection that no one but an educator would see is this: when a man gets to the fourth year and has had no exacting subjects—in fact, I think the plan proposes that he shall not have any very serious subjects until the fourth year, which is reserved for them—the result would be that all would reach the fourth year, and what is to be done with them then? It is a serious matter as it is now, and would be much worse with the proposed plan. We cannot exert sufficient sifting upon them in one year to make sure that we eliminate those who should not graduate and enter the profession at all. I think that these are at least two serious if not fatal objections to any such plan.

In the first, second, and third years there should be some subjects so severe, so analytical, so eliminating as not to allow men to reach the fourth year who should not, and it is still more important not to allow men to graduate to the extent of 50 per cent., or even 10 per cent. who should not do so. This seems to me an important matter, about which any one having experience should give his views, so I state what I think quite frankly, but without any personal application.

H. W. Buck: The two essential elements of any form of technical education are the study of the theory and the study of the practice; in other words, of the mathematical side and the physical side. The study of the mathematical element brings forth the quantitative relation existing between the various forces, movements, and dimensions in a physical phenomenon. Under the department of "practice" is developed a general conception of the physical actions and also of their commercial relations.

It is frequently argued that a student should be carefully grounded in the theory before he undertakes any practical operation or handling of apparatus involving that theory. I believe that this is not in accordance with the workings of the majority of human minds. The study of thermodynamics, for instance, takes little hold of the mind of a man who has never personally handled a steam engine. The mathematical theory of an alternating-current transformer is merely a symbolic puzzle to one who has never had personal association with the current and voltage reactions in a transformer under practical working conditions. The theory of molecular combinations in chemistry is far clearer after a man has actually made such combinations experimentally himself, and so on through many instances.

The same point is illustrated in the history of the development of science and engineering. The experimental discovery of electromagnetic phenomena by Faraday came ahead of Maxwell's theoretical co-ordination thereof. The work of Watt came ahead of that of Carnot. Newton's famous apple was obliged to fall before Newton wove his mathematical theory of gravitation around the physical phenomenon so illustrated, and so on. It all goes to show that naturally in the development of engineering science, as well as in that of the individual mind, the physical action must be clearly pictured before the theoretical treatment can be intelligently pursued.

This sequence is not usually followed in technical education. It is considered orthodox to give a student a thorough theoretical groundwork before allowing him to handle machinery in which the theory is applied, and I am inclined to think that this sequence should be reversed. A clear mental picture should be first created in the mind of the student as a foundation for the theory. The criticism applies especially in the study of pure mathematics where equations, differentiations, integrations, and other operations are studied progressively, sometimes for four or five years purely *per se* without once introducing any practical applications of the performances. As a consequence the mind of the student becomes a maze of symbolic relations and a proper conception of what mathematics is for is lost.

The highly trained theorist who is apt to hold himself aloof from the purely practical man as belonging to a superior class, should not lose sight of the fact that theory is, after all, only a means to an end, the end being the practical application of natural laws for the benefit of man. The practical man who can apply the laws of nature usefully without knowledge of pure theory, is a more useful citizen than the theorist who can not apply his knowledge practically.

In order to obtain the best results in technical education, it would seem advisable for the student of engineering first to become thoroughly familiar through practical laboratory work with the tangible and visible workings of all the principal laws of nature involved in engineering, next to co-ordinate them by quantitative theoretical study of their relations, and finally to take up their commercial application in the study of the design of practical apparatus.

W. S. Franklin: Sir Philip Magnus, in a recent address before the British Association, said that in his opinion education can not be called a science until we begin to study the relations between methods of teaching and the final results accomplished thereby. It seems to me that teachers are, as a body, unable to approach the questions of education scientifically according to this idea, because the results of their work are to a great extent outside of the field of their observation. It is a consequence of this fact, I think, that teachers are especially prone to the elaboration of artificial and formal criteria for judging the results of what they are attempting to do in the class-room. The tendency of teachers to become increasingly formal in their methods and in the materials of their teaching is almost beyond control by the conditions of actual life.

Calling to mind Professor Clifford's statement that education is not an exact science, I wish to affirm the point of view of Sir Philip Magnus to the effect that at present education is not even an inexact science, and I believe that this movement on the part of the American Institute of Electrical Engineers, in which practising engineers and teachers join in the discussion of electrical engineering education, signalizes the beginning of a scientific study of the subject. I think it is out of the question to expect the instructors in our technical schools to weigh the results of their work and to decide whether these results are what they are intended to be. In the institution with which I am connected, for example, we have some fifty or sixty teachers, and among that number there are four or five who have had engineering experience and who have a first hand knowledge of the demands which engineering education is intended to meet. Such a situation, which is common in all our technical schools, makes it impossible, it seems to me, to lift technical education to the plane of a science without the co-operation of engineers and teachers.

I agree entirely with Dr. Steinmetz in thinking that the hope of our technical education is in the narrowing down of our work so as to bring it within the reach of the student. I think that a great deal more stress should be laid upon the elementary sciences, physics and chemistry, and I believe that advanced technical subjects should be taught in such a way as to involve, again and again, a survey of the elementary mathematical and physical sciences which have gone before.

It would be a mistake, however, to curtail the time to be devoted to the first study of elementary physics and chemistry with the expectation that elementary knowledge could be supplied in the development of technical subjects later. The difficulty is that a technical subject, like steam engines, for example, is overloaded with detail; and a technical subject is never given with that accompaniment of simple illustrative lectures and simple laboratory work which is so necessary in the clearing up of the student's fundamental ideas.

Mr. Buck has expressed himself as to the importance of practical knowledge as a basis for theoretical study. I think I agree with Mr. Buck, although I prefer to use the expression "intimate knowledge" rather than "practical knowledge". I believe that the teaching of the physical sciences, reduced to its simplest terms, is *the transformation of intimate knowledge into general ideas*. If this be true, it is necessary to see that a young man has the intimate knowledge to begin with. For many years I have found that young men who come from the farm, or who have had experience in the shop, are very much better prepared for my work in elementary physics than young men who have been through a high school. If this kind of intimate knowledge is what Mr. Buck means by practice, I certainly agree with him, but I would hardly call it practice. The word practice, it seems to me, applies to the functions of an engineer, and what I call intimate knowledge is the knowledge a boy gets by connecting up an electric bell and playing with it until he is familiar with everything about it; or the knowledge a boy gets of hydraulics by building dams in brooks and by swimming and boating; or the knowledge a boy gets of mechanics by riding bicycles and jumping on rapidly moving cars and being nearly jerked in two. This is simple intimate knowledge of the kind that must exist before you can build up the theoretical structure which is called modern physics.

As to what Professor Crocker has said concerning the exacting character of the work in a technical school, I believe that we are now confronting a new situation in technical education. Twenty-five years ago, a man who wished to teach almost any branch of engineering had to reach up into the scientific world, as it were, and take hold of something from Rankine, or Weisbach, or Kelvin or Clausius, and drag it down into the view of his students. How otherwise could a man teach hydraulics twenty-five years ago? or dynamo theory? or the strength of materials? or the theory of the steam engine? Now, however, there is a great mass of simple technical literature exacting and precise. In the old days, mathematics was the only scientific study which could be made definite and exacting. Nowadays nearly every subject which is taught in the technical school can be made as exacting as mathematics, and, above all, the elementary sciences of physics and chemistry have been reduced to a basis which enables these sciences to be handled with an effectiveness which must soon entirely revolutionize technical education.

I believe that pure mathematics is tremendously over-emphasized at the present time in our technical schools. Every one, I think, admits that there is a very large percentage of useless developments in all of our mathematical text-books. A friend of mine, who knows his mathematics thoroughly and has no fear of it (for it is a kind of fear that holds most men in awe of mathematics), and who knows what mathematics means to the physical sciences, said to me several months ago that he believed that at least 30 per cent. of the subject-matter now included in our mathematical courses could be omitted without depriving the subject of a single element of utility for scientific and technical purposes. A mathematical friend of mine, one of the best teachers of mathematics of my acquaintance, has admitted the same in conversation with me. For my part, I believe that 30 per cent. of redundancy is a low estimate.

I think that over-emphasis on pure mathematics is to be found in nearly all of our technical schools, and I think that this over-emphasis involves not only the inclusion of a great many topics which are not useful in physical science, but I believe that it has resulted in a state of affairs which I may describe as follows: of all impersonal ideas the one most strongly imbedded in the human mind is the idea of number. Until the very recent developments of pure mathematics came about, a number always stood for some physical thing or things, beads or fish or dollars or cows, and the result is that *it is extremely easy to hoodwink a young man into the belief that he is studying about real things if his study involves arithmetic.*

I think that one of the most serious faults of our modern technical education is that it is overweighted with a great mass of numerical problems, the data of which are either entirely beyond the student's experience or with respect to the determination of which he is entirely ignorant. Such problems are, to my mind, utterly useless. They mislead young men, and also the teacher, into the belief that something is being accomplished, whereas nothing is being accomplished at all.

To my mind, nothing is more important than to associate physical ideas with mathematical operations and formulas in the work of teaching. In my class-room I have often used the following illustration: consider a wage of $2.00 per day; if you multiply this wage by 10 days you get $20.00. Now I ask my class, "how do you multiply $2.00 per day by 10 days?" but they never seem to have any notion beyond the writing of a simple tabular arrangement on the blackboard. I say, "No; you have got to work 10 days at $2.00 per day in order to multiply $2.00 per day by 10 days and get $20.00". The 10 days of labor is the physical operation that lies behind the mathematical operation, and there is scarcely a single mathematical operation in the whole range of physical science which does not have as definite a physical significance as this operation of multiplying $2.00 per day by 10 days

L. B. Stillwell: The answer to the question, "To what extent should the technical school devote attention to purely professional subjects?" depends upon the relative value to the graduate of professional information as contrasted with education. Undoubtedly professional information may be imparted in such a manner as to educate, but for the purpose of expressing an opinion it is, perhaps, sufficiently exact to speak of "education" and "information" not as they are inter-related but as they are contrasted. Before the question can be answered, however, it is necessary, as Mr. Scott has suggested, to define one's idea of the part which the engineer should be prepared to take in modern life.

As regards this, the conception which apparently is widely accepted, not only by preparatory and undergraduate technical students but also by many "over-practical" parents is narrow and short-sighted. The enormous advances in physical science, and in the application of physical science to modern life, are glibly asserted and reiterated, and the effects of utilization of natural laws and forces upon the economic and social structure of society are more or less appreciated. But in educating a boy for the special purpose of taking an active part in this gigantic movement, the tendency too often is to start him at the earliest possible moment in a narrow channel of thought, to narrow his intellectual horizon and make him a mere mental mechanic. This, in my opinion, is all wrong.

If graduates in engineering courses are to become generals, or even colonels, in the army of engineers it is obvious that the breadth of their training should bear some relation to the fundamental possibilities and demands of the field in which they are to labor. The engineer who desires to rise, therefore, should start, if possible, with a broad education. Truth is truth, fallacy is fallacy, and logic is logic, in any field of thought. In nine cases out of ten, mere professional information acquired in the technical school is of comparatively little value to the graduate. This is particularly true in the case of a rapidly advancing art such as electrical engineering, for the reason that a considerable part of the professional information acquired in school is out of date by the time the graduate attains a position where he has opportunity to utilize it. Practical information which he can really utilize is acquired rapidly in factory or office, in mine, mill, or laboratory. Following graduation, the work which young engineers in almost all cases are called upon to do for a number of years is highly specialized and professional information comes to him in the most effective manner. During these years, if he is working earnestly for advancement, his field of observation and thought, so far as his professional work is concerned, is necessarily limited and comparatively narrow. The opportunity for fundamental education rarely presents itself after completion of the course in the technical school, and unless prior to that time a broad foundation has been laid it never can be laid.

The ideal education of the engineer who hopes to be more than a private in the ranks is a broad one. It cannot very well be too broad. In my judgment, whenever possible, a technical course leading to a degree in engineering should follow a four years' course leading to the degree of bachelor of arts or bachelor of science. In other words, engineering courses should be regarded as professional courses and should perform the same function in the education of the engineer that the law school fulfils in equipping a graduate in the course of arts for the practice of the law.

In those cases where this is not possible, and the student finds himself necessarily limited to a course of four years in a technical school, the aim should be decidedly to educate him rather than to train him.

In my experience the following facts of observation have impressed themselves upon me:

1. American engineers to-day do not hold positions of leadership in the community to an extent commensurate with the part which engineering plays in modern life.

2. The graduates of our technical schools, while averaging well in respect to mental ability and earnestness, often lack mental perspective and are rarely capable of expressing themselves with accuracy and force.

3. The men who rise highest in the engineering profession, generally speaking, are the men of broader education.

4. Chief engineers and managers have little trouble in finding draftsmen, and less in finding competent calculators, but the demand for "all around men" always exceeds the supply.

5. The higher executive positions in administration of our great railway and industrial corporations are rarely held by engineers. In recent years undoubtedly the engineer has been making substantial progress in this direction, but usually he fails to occupy his share of the higher places in administration.

So much for personal impressions based upon observation of results. As to methods, I cannot presume to offer advice to the teaching profession. It would appear obvious, as Mr. Scott says:

> That details of method are to be determined by varying conditions and are to be adapted to the varying personal qualities of the young men.

I would particularly endorse what Mr. Steinmetz has so ably said in regard to that fault of teaching which aims at quantity and not quality. There is no good reason to believe that the ability of the human race to acquire and digest knowledge has increased abnormally during the last decade or two, but comparison of requirements in colleges and preparatory schools to-day compared with the curricula of 20 years ago, indicates that our educators are proceeding upon the theory that the average student of given age to-day is endowed with mental capacity greatly exceeding that of his father, not to mention his grandfather. The result in a great majority of cases is mental indigestion from which the student sometimes, but not always recovers, after graduation.

The cause underlying this unfortunate and very serious state of affairs is to be found probably in the ill-advised competition of schools and colleges. The school of the future is the school which will have the courage to cut out of its curriculum 25 per cent. of the studies now required for graduation and will emphasize not quantity, but quality.

Albert F. Ganz: Dr. Steinmetz says that:

> The least that can be expected from the college is that at the time of graduation, the student still knows all that he has been taught during his college years. To accomplish this, it is necessary to keep up the study of every subject to the end of the college course.

This seems impracticable. How are we to cut out some subjects and have less quantity, but yet to keep up every subject throughout the whole college course? I expect Dr. Steinmetz does not mean this to be taken literally. For instance, I do not suppose he thinks that the subject of chemistry should be taught to the end of the college course.

Chas. P. Steinmetz: I do.

Albert F. Ganz: Then I should very much like to know how we can cut down the course and yet keep up the study of every subject throughout the four years?

I have read Professor Karapetoff's paper carefully, and while the method has many good points, I feel very strongly that the college is the place where theory must primarily be taught; and that this theory must be supplemented by illustrations from practice by means of descriptive lectures and laboratory work.

I believe that there are four objects to be accomplished by a technical education: first, training of the mind so that it becomes an efficient machine; secondly, storing in the mind fundamental principles and facts to give to the student an understanding and a perspective of his profession; thirdly, an acquaintance with the sources of information so that the student may know where to find information; and fourthly, general culture. It seems to me that in the college we should aim to teach those things which the engineer must know, and which he cannot readily obtain in practice, nor from general reading. As an example, the mathematical theory of alternating currents should be taught in the school, because in practice the engineer would not learn that theory nor would he readily be able to get this from his own reading. I also believe that the laboratory experiments should be designed primarily so as to impress upon the students the main fundamental principles, not designed to imitate the tests that have to be performed on the test floor of a large manufacturing establishment. I do not believe that the latter is possible in a college laboratory. That is an example of the kind of information which the engineer can get from practice. I always advise our graduating students to spend one or two years after graduation in the shops of one of the manufacturing companies. Fortunately for the technical schools, the large electrical companies have established apprenticeship courses where it is possible for the student, after graduation, to become familiar with large machines under commercial conditions.

I should like to have the Educational Committee suggest what cultural subjects should be included in the curriculum, and how much time should be devoted to them. At the Stevens Institute we include in our curriculum courses in business engineering, English, German, and some lectures on patent law and on contract law, and we hope to include more cultural subjects.

Mr. Buck speaks of teaching the design of practical apparatus. I question whether in a technical school it is possible to teach practical design to any considerable extent. I rather agree with Dr. Steinmetz, that it is better to analyze existing apparatus than to attempt to make actual designs.

J. G. White: There seems to be a virtual unanimity of opinion, that the aim of the college education for engineers should be to build up a foundation or groundwork based on the fundamental subjects of which the engineer should have knowledge, rather than to give him specific information. I fully agree as to the thorough wisdom of this. Specific information can be readily acquired after leaving college, whether it be with one of the large electrical companies, or in a consulting engineer's office, or out in the field in erecting machinery, or elsewhere. The fundamentals, such as a good general knowledge of mathematics, and a thorough knowledge of physics and chemistry, both of which I consider extremely important, cannot readily be acquired in the field; that is one of the reasons why they should be acquired during the college courses. The subjects that are useful primarily because they are a benefit to one's general culture are less readily acquired in practice, partly because the facilities are not so conveniently at hand and partly because one is likely to be absorbed in the performance of daily routine duties, so that it is difficult to find opportunity to put thorough study on subjects not requiring attention by reason of such routine duty.

So far as the general usefulness of different subjects is concerned, it seems to me that, as intimated in the previous statement, there should be a thorough and broad training in mathematics, in chemistry, and in physics, and I believe with Mr. Steinmetz that all three of these can be carried through the college course. No one should specifically study calculus during the entire course, nor specifically study elementary chemistry during the entire course; but in the later studies, dynamo design, for example, enough calculus can be used advantageously to keep one from forgetting the general principles of calculus, and so one can, in the study of electrochemistry, in connection with experiments with storage batteries, or in other like ways, have enough use for chemistry to prevent one forgetting the elementary chemistry learned in the freshman year. In similar ways, if a course is laid out correctly, one can be kept from forgetting other subjects which have gone before. In addition to English, which I am glad to see is being followed up more consistently and persistently, one of the subjects which I perhaps am inclined unduly to value is the study of Spanish as compared with other language studies. It seems to me that Spanish has practically as much educational value, and almost as much value as a culture subject, though perhaps not quite so much as French or German; but it is so much more likely to be of use in practical life after graduation, that I strongly favor the average engineering student studying Spanish, if he possibly has the opportunity of doing so. If he can study one other language, Spanish as a second is distinctly desirable. It is a comparatively easy language to learn.

Another suggestion which perhaps our friend from Stevens may like to hear in plain English is that ordinarily I believe the college professor is too much inclined to rely on lectures and too little inclined to depend on well-worked out, well-planned text-books which some other professors, or groups of professors, have written. The lecture room is of great value in physics, chemistry, and in electrical engineering, for illuminating and illustrating fundamental principles, but these fundamental principles should be put before the student in such shape that he has something to study and restudy, can have impressed on his memory. His time should not be wasted by making a lot of notes and going through the mechanical operation of copying them, when, after he has them copied, he probably has no adequate understanding of the subject. Another beneficial trend of many general educational courses is toward doing away with too great freedom in elective studies. About the time I left college there seemed to be a great tendency toward putting all students entirely on the elective system, leaving nothing on the required curriculum. There seems to be a drifting back to the good old-fashioned days of mapping out a set course for young men, and I think that practice can be advantageously followed further than it has been. It seems to me that a group of professors in consultation with other officers of an educational institution, and with the advice of graduates and trustees, can decide to better advantage what the ordinary engineering student of 17 or 18 years of age should study, than can the young man himself. That is surely true of technical courses, and I should be glad to see more text-books, fewer elective studies, and the required studies more confined to general principles and foundation work and less given to doling out general information.

W. E. S. Temple: There is a noticeable tendency on the part of those who have been out of school for ten or twenty years to overestimate the amount of preparation which the technical graduate should have. In considering the subject, it is necessary to try to state what the object of an engineering education is; we can then see better what it should consist of. It is admittedly impossible for a man still in school to know just what line of work he may be best suited for, yet this is the age of specialists in electrical engineering, as well as in other professions and on this account the object of the technical training should be to provide the man with the means to receive the best development in that special kind of work into which he may be placed after graduation.

The education must therefor consist in grounding the man in principles and general applications. This will give him the tools with which to develop himself when he becomes enrolled in the school of experience. A great many rules and formulas have been suggested, indicating how best to accomplish the laying of this general foundation for development, but rules and formulas cannot be applied here any more than they can be to regulating the politics of New York or of Philadelphia. We must set before ourselves a certain aim, and keep examining ourselves as to methods, taking account of stock as it were, and make sure that we are getting the best results possible.

Another thing that should be accomplished in addition to getting a thorough foundation in technical principles, is lifting the man's ideals high as to his future position as a man of affairs. There is no reason in the world why the engineer, who is responsible for so large a proportion of the wealth and resources of this country, should not have more control over them, and more profit from them.

The quality of the work done by a student actually depends upon himself as much as it does upon his teachers, and therefore the entrance requirements deserve as much attention as does the laying out of the work after he begins his technical training. To outline the actual subjects which should be taught is not difficult. There are a number of lists which are in use, some preferable to others, but all of them good, for they are producing favorable results. It seems to me there should be more of those subjects which develop the man's power to reason along lines related to engineering, and less of those which fill his mind with a useless store of technical data that can be found in handbooks. As to the suggestion in Dr. Steinmetz' paper that physiography, metereology etc., be taught; why not a course in architecture and perhaps practical politics too? These are really as much related to the subject of engineering, and are as broadening, as the subjects he refers to, perhaps more broadening. It seems to me that specializing is not preparing the student for the best development, and a too great indulgence in it prevents the college from doing the greatest good for its men. I am referring, of course, to the undergraduate students.

One of the vital features in the education of the engineering student, it seems to me, is the method followed in taking up the work. Mr. White referred to the matter of lectures; I do not think that any hard and fast rule can be laid down for this. The rapid progress now being made in electrical engineering demands that some of the subjects relating to the applications of electricity be taken up in lectures. I know of no text-books in existence at present which are suitable for this part of the work. The elementary subjects, and the general applications of electricity should, in my opinion, be invariably taught by the use of carefully selected text-books concurrent with the solution, by the student, of various kinds of engineering problems. These problems should involve not only the new ideas and principles as they are taken up, but they should also depend upon subjects already gone over in earlier parts of the course. The classes should be subdivided in sections of about ten men each for all recitation work, thereby insuring more nearly individual instruction, and making it possible for each man's needs to receive attention. The greatest stress should be laid upon promptness and accuracy and general attention to work. The student should be penalized for absence from classes, or for tardiness in doing the work assigned to him, even though he may do that work in a most satisfactory manner from every other standpoint.

Laboratory work should be individual as far as possible. If the men work in groups of two or three or more, upon one test, it is not possible to make sure that all of them get all the benefit which they should have from the work. The inferior man will allow the better man to do it all, nearly every time. The only sure cure for this is to make each man work alone. This method is, no doubt, more expensive, but if the thing is worth doing at all, it is worth doing well. Furthermore, the best results will be obtained if each man is obliged to set up his own apparatus, and wire up his own test. If he is a particularly good man, it is not a bad idea, occasionally, to put the machine in trouble in some way or other; this method will require more time for each test, but quantity is not what we are aiming at; it is quality we are after, and this method is bound to produce a far higher grade of work, and to develop in a much greater degree, the man's thinking, and reasoning powers.

The method of concentric instruction has been very adversely criticised, and it seems scarcely necessary to speak of it any further. The idea, if applied to one subdivision of one of the subjects of electrical engineering, might be good. It is however utterly impossible, as has already been pointed out, to go into details of construction and operation of machinery, particularly electrical machinery, without having the theory to resort to for explaining the why and wherefore. As I understand it, this method proposes to complete all the practical considerations first, leaving the theoretical features until last. The result of this would be that in going over the practical parts with no theoretical preparation the man would perforce become a confirmed empiricist, and when he came to the theory later on, he would be perfectly satisfied to omit it entirely, or at least he would fail to give it the proper attention. The summary of the paper shows a great many things which this concentric method will accomplish; it will produce a somewhat finished artisan at the end of the first year, a little better artisan at the end of the second year, etc. It reminds me of a machine that will do a dozen different things, but none of them properly.

Louis A. Ferguson: The great value of an engineering education to a young man about to start in his life's work lies not so much in the actual knowledge he may bring with him, but in the training which he has received. The accumulation of a mass of data is not the important thing, but the reasoning power which he has acquired is what will serve him in good stead in after life. The technical training of our engineering schools develops an analytical turn of mind and teaches the young man to differentiate between right and wrong, promotes sound judgment, which, after all, with initiative and optimism, is one of the great factors in producing the successful man in any walk of life.

It is a mistake, as Dr. Steinmetz has clearly pointed out, to try to jam the maximum amount of information into the student in one year, only to be forgotten the next. Premium should be placed upon the development of reasoning power rather than thé mere memory of the student, and any subjects that he must know in his practice after graduation should be kept constantly before him throughout the entire course, so that he may carry his knowledge, once acquired, with him into the world.

There is a tendency in some educational institutions to a practice which I think is not conducive to the best results. I refer to what might be called "inbreeding", that is, the general employment of graduates of a given technical college as teachers and professors in that college. This promotes narrowness of view among the students, mental fatigue among the teachers, resulting in the decline of the educative ability of the institution. The faculty of an engineering college should be made up of men graduated from as wide a range of colleges as possible. Eastern colleges should have some professors who have been trained in the West and South, and western colleges should have professors who have been trained in eastern institutions, so as to give as broad a character to the education as possible, and to keep alive in the faculty itself real interest in its work.

We find in the management of industrial corporations that the best results are obtained by following this principle in the employment of engineers. The very college patriotism which exists in the heart of every true American will prompt him to try to equal in efficiency his fellow engineer from another institution, and this rivalry, which must be friendly to accomplish the desired result, is bound to make finally for the interest of the corporation.

Professors and teachers are not as a rule sufficiently encouraged by their college management to come in contact with the practical side of engineering, or the work accomplished in other similar institutions, as they might be were they given the opportunity to mingle more with practising engineers and industrial managers and by travel in this and other countries. They are, as a rule, forced to gather their information by reading and study which is less satisfactory than actual contact and observation.

Why, if the industrial corporations find it profitable to send their engineers and managers to other parts of this country and Europe to study conditions and make comparisons, should not the technical colleges and institutions find it equally so to do the same with their teaching staff?

The scope of the course of electrical engineering in some institutions, it seems to me, is too narrow. The graduate electrical engineer, for some reason, is considered by some employers to be devoid of ability to discuss anything but electricity, and his opinion on other matters is discounted and oftentimes very unfairly to him. This is unfortunate, as there is probably no branch of engineering which requires so general a knowledge to be successful as that of electrical engineering.

The course in electrical engineering should include the fundamental principles of mechanical engineering and civil engineering, chemistry and hydraulics, building construction and general business law, as well as theoretical and applied electricity. The student should be impressed with the fact that a general fundamental knowledge of the branches of engineering other than pure electrical is paramount to ultimate success in electrical engineering, if by that we mean obtaining a position whereby one is given the responsibility of conducting large engineering undertakings, or the management of large industrial operations.

Samuel Sheldon: That educational institutions are unable to obtain the best type of instructors because of the low compensation which they offer is recognized by professors, by those who wish to be professors, by engineers, and by the presidents and trustees of these institutions. The mere announcement of the fact will not better the conditions. Much could be accomplished by a co-ordinated movement on the part of all technical institutions to increase the tuitions from students who are able to pay, leaving the funds which are derived from philanthropists to be distributed, so far as they last, in defraying the expenses of worthy and selected students. In reference to quality, as distinguished from quantity, the Educational Committee of the Institute would perform a useful service if it should bring about a curtailment of the matter which is at present presented in connection with the instruction in each and every subject in existing courses. Such curtailment, in view of the fact that courses will doubtless be limited to four years for some time to come, would result in a saving of time which could be utilized for needed culture subjects, and for the amelioration of existing conditions towards which the so-called concentric method of education is directed.

In reference to Mr. Scott's paper, the extracts from the Institute papers are on the whole so general as to be of little value to one engaged in laying out a curriculum. One, however, and that is from the paper presented by Professor Karapetoff, is very definite, and the original is accompanied by a specific schedule for each year. The advantages which it is claimed would result from the use of this concentric method should be obtained, if possible, but it does not seem necessary to make use of such radical means as are outlined in that schedule. Associated with it are two marked disadvantages: first, the hiatus in the pursuit of mathematical studies must inevitably result in educational inefficiency; secondly, training in physics, which is an absolutely essential prerequisite for any serious engineering study, is deferred to too late a period.

Tests of the absorption power of an average freshman indicate that a cyclopedic view of all engineering could be profitably given during the freshman year without consuming more time than could be obtained from a judicious curtailment of the freshman schedule, as at present existing in most institutions. Experimental electrical engineering is also required early in the concentric schedule. Physical laboratory work could readily be so laid out as to constitute a course in experimental electrical engineering.

P. H. Thomas: In its broadest sense, engineering is a method, not a profession. By this view, "engineering" is the application to new problems, through the methods of logic, such as mathematics, the knowledge of experiment, and experience. This method is applicable to many branches of activity not included in a narrow definition of engineering. There is every reason why the banking, trading, and selling work of the country should be carried on by men trained as are mechanical, electrical, or civil engineers, but in a different subject-matter. In fact, this state of affairs seems to be rapidly approaching.

Although the object of technical education must be, strictly speaking, to perfect a man as an engineer, expediency requires that at the same time he must receive such culture training as he is to get at all during the same period. The man should by no means be sacrificed to the engineer. Fortunately, such culture training as is appropriate will usually benefit the engineer. The factors of greatest importance underlying successful engineering are perhaps the following:

1. A thorough appreciative knowledge of the laws of nature and of the properties of materials. These laws and properties, as used in engineering, are simple and relatively few.

2. Familiarity with the mathematical and other logical processes by which the fundamental laws are to be applied to special cases and results numerically computed. Here self-confidence and the power of applying knowledge are of the greatest importance. It is here that many graduates are lacking. This section must be construed very broadly to include the underlying principles of all types of machines.

3. Familiarity with the results of experience; what has actually been accomplished in the past and just how. This is of the greatest importance and is, further, the basis of the great mass of actual engineering work done. The results of past work are found partly in the general practices of the community, partly in books and periodicals, and partly in the records of individuals of experience. Here should be included, at least for the more ambitious engineers, a knowledge of the more important experimental work done and the new methods and apparatus proposed by inventors.

4. Acquaintance with the actual methods, standards, practices and engineering terms in vogue in any particular community. These may be different in different places; but one engineer can not work with another without this acquaintance.

Over and above these four conditions the effectiveness of an engineer depends, of course, on his personality, but this is not properly a matter of education.

The actual period of an engineer's development in which he may be said to be receiving his education is perhaps ten to fifteen years, beginning with his technical school work. Of this period, four years are usually devoted to school work, a good proportion. Here comes the practical question to be considered: to what shall these four years be devoted? In my opinion to the first and second and to the more fundamental facts in the third division of engineering knowledge just given, and as well to some culture studies.

The study of natural laws, of the characteristics of materials and all mathematical work is best done in class work. Here should be included the laws of force and motion, of heat and sound and electricity; such subjects as mechanism and mechanics and thermodynamics. Also, for electrical engineers, such information as the laws of parallel circuits, induction, resonance, wave motion, the natural characteristics of different types of electrical apparatus intrinsically, as transformers, series and shunt motors; also principles of compounding, field distortion, etc., induction motors, synchronous machines, etc. But not such subjects as commercial designs or designing of apparatus, constants of design, the relative merits of different makes, physical description, compilations of actual costs, efficiencies, and other data of actual plants, nor much study of actual installations. These all tend to distract and to lessen interest in the more fundamental things that cannot be learned later.

The subject-matter here assigned to the school years is in the long run of the greatest importance and cannot be well gotten later. The other subject-matter covered in the four divisions of engineering knowledge is readily acquired in actual practical work, but only with the greatest difficulty in the class room, and then imperfectly.

The engineer must specialize, even within the divisions of civil, mechanical, electrical, etc. The specialization should not however prevent an appreciative knowledge of all other important branches. As Dr. Steinmetz has said a good descriptive short course can give a group of fundamental phenomena, and the essential or individual character of such a branch in a way, that will permit a real appreciation of its significance. The influence of these related branch studies is tremendously broadening.

It is not for the practising engineer to specify in detail the course of the technical school, this is for the specialist in education, the professor; but the engineer may suggest a measure, by which a course may be judged. The following is an example. Does the course give:

1. A clear, thorough, appreciative knowledge of the natural laws used in engineering work. Also, a good knowledge of the properties of materials.

2. A clear, working knowledge of the mathematical methods, formulas and other logical processes by which the fundamental laws can be applied to individual cases and numerical computation made. Also, a familiarity with the characteristics of the sorts of apparatus commonly used (not commercial types) in electrical work—transformers, motors, generators. Is the student's knowledge and training of such a character that he can personally use his data and formulas and have confidence that he is right?

3. Has the graduate enough general culture to feel the equal of and at home with the other men (not necessarily engineers) that he meets?

4. Has the matter been so presented as to be grasped in the easiest and most permanent manner? Has the interest been kept up and the meaning of the work made clear by some view of the practical field into which the student is to pass?

W. L. Robb: A matter that has an important bearing on the curriculum of engineering schools, but not mentioned this evening, is the relative lack of preparation of men who enter these schools. It is a notorious fact that the great majority of men who enter technical schools have not completed a high-school course. Men generally enter the technical schools at least a year before graduation from the high schools. Virtually all the technical schools have lower entrance requirements than the colleges. Where the requirements are nominally high, the examination in the non-mathematical subjects is relatively easy, the examination in mathematics being the real basis of entrance. The majority of men entering medical and law schools at the present time are college graduates, much more highly trained than the men who enter the technical schools. As a result, a large part of the first two years in the technical schools has to be given, not strictly to engineering subjects but to general mental training. Under the present condition of things, culture subjects have a place in a technical school, but I believe they only have a transient place. I do not think that a course in English or history or political economy has any more place in a technical school than in a medical or a law school. We should see that the entrance requirements of the technical schools are brought up at least to the entrance requirements of the colleges.

With entrance conditions as they are at present, the first two years of a course should be mainly given up to the study of mathematics, chemistry, physics, English, and one other language, preferably a language that is inflected. I do not think it makes much difference whether the language is Spanish, French, German, Latin, or Greek. As far as the commercial usefulness of the language is concerned, I believe thirty days spent in a foreign country will prove more valuable than two years' study of the language in a school.

The third year of the course should be devoted to mechanics and the fundamental principles of civil, electrical, and mechanical (including steam) engineering. There should not be much, if any, difference in the way these subjects are taught in the various engineering courses.

The fourth year I would devote mainly to highly specialized subjects in that branch of engineering in which the student elected to take his degree. The student should have the privilege of specializing along some desired line before graduation.

I do not think we should have in engineering schools courses specially devoted to business methods, depreciation, operating costs, and similar subjects; but I think any man capable of being at the head of an engineering department should infuse these subjects into the minds of his students in connection with the regular work.

C. O. Mailloux: I have, presumably, at the present time, all of the qualifications for speaking on this subject, since I am a practising engineer, and, at the same time, happen to be an "amateur" teacher in one university, and an "amateur" student in another. The complete period of instruction of an engineer, which Mr. Thomas speaks of as being fifteen years, is too short for the man who believes in progress. I find that it can be profitably extended to at least twice that time.

I agree fully with Mr. Stillwell. His discussion states the facts, from the standpoint of the enlightened progressive engineer, very well indeed. I endorse his plea for broader education, now, just as I did at the Great Barrington meeting. Like him, I have found, and I so stated at Great Barrington, that, oftentimes, the man of broad general culture is of greater utility, and makes more rapid progress, than the man who specializes too soon. I also agree, with him, that there is an abundant supply of the mediocre man, but a scarcity of the man able to do original work. In looking for the causes, we find that there are many, and in looking for the remedies, we find that they are diverse. Yet, after all, we find that the general principles have already been reviewed in previous discussions; and I noted, with some interest, as the discussion progressed, and as I classified the points covered, that most of the formulated statements regarding the requirements of technical education have been given already, in previous discussions before the Institute, particularly in the papers of Professor Esty and of Dr. Sheldon. Professor Esty gave, in his paper, a resume of the requirements, so well, that, even after the discussion here tonight, we do not find that we can improve much upon them. Dr. Sheldon's discussion differs from Professor Esty's only in so far as it goes further, or attempts more. It aims to build a "pyramid of knowledge" of greater height, and therefore postulates a broader base. I have already spoken of that pyramid fully, in my discussion, at the Great Barrington meeting; and I need only add now that my views have not changed in regard to it. In that discussion, you will also find a reference to the subject of "mathematical dyspepsia" which, I think, is still pertinent. There is nothing which causes so much contention and dissatisfaction among teachers, students, and engineers, as the teaching of mathematics. A great deal of effort has been devoted to finding better methods of teaching mathematics. I am often questioned by both teachers and students of engineering about that subject. I expressed my views fully on that subject at the Great Barrington meeting. I also made some reference to the views of Dr. John Perry, who has some perhaps radical, but very good, ideas on the subject. I am glad to say now, that the ideas of Dr. Perry have actually led, since then, to wholesome reforms in methods of teaching mathematics in England.

My own view about engineering education is that we should attempt much less, and yet, attempt much more. We should attempt less in not trying to cover so much ground and so many details, but we should attempt more in trying to cover fundamental ideas and principles more thoroughly. I often find that students are bewildered and discouraged by the size of the text-books given them. If the text-books were smaller, or less terse or rigorous, if they covered fewer points and covered them more thoroughly, they might, perhaps, be less imposing, but they would be more "effective" as repertoires of knowledge for engineering students who do not expect to become teachers.

On the subject of lectures, as distinguished from text-books, I may say that my experience, both as a teacher and as a student, leads me to believe that the ideal method is to combine the best *features* of both. I believe in a method in which the student receives guidance and instruction primarily, and whenever possible, from lectures, but works in connection with text-books, or, in the absence of text-books, (and, *preferably*, in all cases, when it can be done), with a carefully prepared up-to-date, and not too much condensed, syllabus. My own method in teaching, is to ask the student to take as few notes as possible. I try to give them ample ready-made notes of all the principal points and all the main details of the discussion; and I also refer them to all books which can be of assistance to them by throwing more light on the subject. I know, by personal experience, how often one makes errors in taking down notes and how difficult it is to correct notes taken down wrongly.

In regard to the teaching of mathematics, pure and applied, there is danger that, while trying to cover the moderate wants of one class of men, we may neglect to cover the higher wants and aspirations of another class. We must consider the kind of material that we work with, and the kind of men that we expect to turn out. It all depends on how high the pyramid of knowledge is to be built. If we seek merely to turn out mediocre or average men, we can get along with relatively little training; but if we wish to turn out men who are to be colonels or brigadier generals in the profession, then we must place at their disposal the facilities whereby they may acquire that higher training which they should have. It may be that we cannot do both of these things in the same class, or even in the same school. At this point let us say a word about the distinction between theory and practice. I think that too much emphasis is laid upon the importance of the student being brought into physical contact with those facts which he can gather with his eyes and hands. Any person who has given the slightest thought to education knows that it is not so much the facts which are discovered by the eyes and hands that are important, as it is those which are discovered by the mind. There are certain "facts" which are more important than even the individual, oftentimes detached, physical facts, gathered by the hand or the eye; and those higher facts are called principles. These are usually the facts which furnish the key to whole treasures of facts. Thus, while it is true, as Mr. Buck said, that Watt came before Carnot, yet, it is also true, that Carnot came before Corliss. We also know that Hertz came before Marconi, just as Maxwell and Faraday came before Hertz. There is an important distinction to be made between the use of mathematics as a means of technical training and as a means of technical research. There is a legitimate use for both. We may possibly have done too much in the way of using mathematics purely as a means of training for engineering students. We should, in the training of engineers, perhaps, use more applied mathematics and less pure mathematics. But here, again, we should bear in mind the needs of the higher technical science and look to the great engineers to see what they have done as the result of specializing and higher training. The distinction of a school is due partly to the distinction attained by the great men who received their training at that school, and partly to the distinction of its teachers. It is worth while and is inspiring to look at some of the great achievements in our profession, and to see the means whereby they have been attained. Some of these things are of the greatest significance, and they point to a moral in regard to methods of teaching and the way it should be directed. Two of the greatest achievements in electrical engineering, in my opinion, have resulted from the solution of differential equations. They are feats of applied mathematics. The first of these achievements was made when that great electrical engineer, Lord Kelvin, solved the differential equation since known as the " telegrapher's equation ", and, in doing so, predicted all that it was essential for us to know, and foretold the facts and the practical essential conditions that were afterwards observed, in regard to submarine telegraphy. That solution was the key to submarine telegraphy. The second achievement was another solution, a far more complete solution, of that same differential equation, by Dr. Pupin; and this latter solution, which turned out to be the first general solution, has done almost as much for telephony, as the solution of Lord Kelvin had done previously for telegraphy. These two cases show that, when the greatest results in electrical engineering are the goal, even the most complete equipment, intellectual or technical, is not too great. As to what constitutes the modicum of requirements which a student of engineering should satisfy, my opinion is that these requirements include three or four principal branches. I might say that, of physics—the fundamental physics of energy in all its forms and manifestations—the student cannot have too much. He might have too much physics if he is led into the by-paths of physical research too early, but of fundamental physics he cannot have too much. If we include mechanics and chemistry in physics, then we may say that the principal part of the engineer's education should be physics. Let us say, then, physics, mechanics, and chemistry; and let us not forget mathematics; but there should not be so much pure mathematics as applied mathematics; there should be just enough pure mathematics to enable the student to get along in applied mathematics. I believe strongly in analytical mechanics and even in some mathematical physics, both of which are applied mathematics, with physics. In a word, I believe in plenty of fundamental physics, taught both ways, experimentally, and also by mathematical methods. Too much time is spent in teaching mathematical abstractions which the students cannot possibly remember. The pure mathematics should include the essentials and fundamentals of algebra, geometry, trigonometry, and the calculus, leaving the refinements thereof for later attention on the part of the student, after he has learned to appreciate their value. I cannot quite agree with Professor Robb as to the transient features of culture in the curriculum. He contradicts that opinion himself, to some extent, when he says that facilities should be given to students for specializing, since specializing is a means of broadening the student's culture. One of the sad facts which should be realized more than it is, is the want of general culture in the engineering profession. Mr. Stillwell has brought that out clearly. I believe, with Professor Robb, that one of the most important difficulties lies in the fact that the students are placed in contact with the engineering part of their education too early, before they have had the necessary amount of preparation, or even, I might say, of intellectual growth and development. Perhaps the solution of the entire problem will be to increase the requirements in regard to the preparatory studies pursued and to apply an inferior limit to the age at which students are allowed to enter the polytechnical courses. We should not expect to make children engineers, any more than to make them doctors or lawyers. One remark of practical importance is that made by Professor Clifford, in reference to a committee of engineers acting in consultation with the faculty or the heads of the departments. There may be a great deal of good there; but there is also a possibility of harm. I know, from having seen men teach, that there is as much difference in teachers as there is in pupils and I know also, from having attended lectures by "outside" men, so-called, that some of these lectures are apt to be quite as bad as they are apt to be good. I mean that the practical man is "fit" as a teacher only when he has retained such contact with the theoretical side of his profession that he can still be able to lead instead of mislead the student, when he presents his subject to them. I have seen cases of that "misleading" kind which brought home to me the lesson that he who undertakes to teach practice, must know thoroughly the theoretical part as well as the practical part. The man who undertakes to teach theory alone may get along with little, if any, knowledge of practice at all: but the man who undertakes to teach practice must know both the practice and the theory.

The idea of segregation, which was referred to, seems an excellent one, and it may be that the future will lead to it by a natural process of evolution. There has been some suggestion made, in fact, of technical schools which would be devoted to advanced technical teaching, either by taking men who meet higher entrance requirements, or by lengthening the course, In that way, by having the high grade men in a different class or school, we would be able to train high grade men so as to make them attain the highest efficiency.

Philip Torchio: Neglecting the all-important questions of individual talent, commercial acumen, and executive ability, which are mainly acquisitions by birth and surroundings, we may classify the students of engineering into two classes: one pursuing a college course to master the technical engineering knowledge, aiming to apply it directly in the conception, design, and carrying out of original engineering works; the other acquiring that knowledge as a means of securing a better class of employment or as a stepping-stone to commercial, industrial, or financial pursuits. Theoretically, the education of these two classes of students should be essentially different; the first requiring for his career a greater equipment of mathematical and theoretical training than the latter, for whom the practical side is of much greater importance. The measure of professional success in their respective fields of activity is in one case the amount of retainer and consultation fees, and, incidentally, social prominence; in the other it is the salary received or the increment profit secured by the commercial exploitation of any specific independent industry. If the two classes of students must be put through the same courses, I think that we would come to the conclusions reached by Professor Karapetoff, as a matter of expediency if not as a matter of choice. Professor Karapetoff's method will appeal most to the managers of industrial corporations and the majority of employers of engineering skill. It is a striking fact that most of the leading positions in industrial enterprises are to-day not filled by technical graduates. A few years ago about forty high officials of a large manufacturing corporation were seated at a dinner, and among all of them none was found to be a college graduate. As this corporation is considered here and abroad a model organization, such condition of affairs should command the earnest considera tion of educators.

Conditions will change, I might say are changing now, but the progress is slow. We must, therefore, place our aims high, but not forget the local and present conditions, demanding highly specialized and practical knowledge. Our great centralization of industrial interests makes still more necessary a greater refinement of specialization than exists abroad. We may all deeply regret this narrow-gauge education, but we are leading the world into this condition. The great number of young electrical engineers are affected by these conditions. On the other hand, this very high degree of progress and specialization, combined with the importance and magnitude of the engineering work done in this country, creates a demand for exceptionally high engineering standards on the part of the relatively few leading men who pilot the heavy engineering and scientific work of the country. These different requirements make the problem of technical education more difficult. Now, if we must specialize, and we have the resources for doing it, why should not the colleges for electrical engineers also specialize, and equip themselves, some to turn out practical engineers fitted to fulfil the positions in industrial enterprises, and some to turn out electrical engineers with a much broader theoretical and scientific education, befitting the requirements of the broad engineering profession. The only obstacle that I can see would be an ill-placed jealousy among the different colleges.

I have no doubt that eventually we shall come to such results, as present indications point clearly that way. The majority of colleges will continue to bring into greater prominence the immediate practical applications of each engineering branch. On the other hand, a few other colleges more favorably situated will develop along more scientific lines, aiming to give a broad engineering education, possibly branching out into specialized electrical studies only in the last one or two years of the course.

I have the privilege of giving the experience of the Royal Polytechnic of Milan, Italy, which was started forty years ago along the lines of broad engineering education I have just referred to. About twenty years ago a course of electrical engineering was established through the private endowment of Carlo Erba, as an adjunct to the Polytechnic. The Polytechnic is a government institution but created mainly through the efforts of the late Professor Brioschi, a man of rare talent and ability, who imparted to the organization a good deal of his strong personality. The essential requisites for admission are the government certificate either of an eight-year preparatory course in a lyceum, in which classical studies prevail, or a seven-year preparatory course in a technical institute, where physical and mathematical studies and modern languages predominate. The average age of a freshman class at admission to college is about nineteen years.

The engineering course consists of five years, the first two being preparatory to all engineering courses, and the last three being sectionalized in three classes of civil, mechanical, and electrical engineers. The first two years cover a thorough study of the calculus and higher algebra, analytic, descriptive, and projective geometry, general chemistry, mineralogy, physics, drawing, etc. In the next two years the mechanical and electrical engineers jointly follow, theoretically and experimentally, the studies of mathematical mechanics and applied mechanics, theory and design of steam, gas, and water power prime movers; design and calculations of parts of machines, resistances of materials and general construction, hydraulics, organic and inorganic chemistry, surveying, descriptive study of industrial plants, such as foundry and working of metals, cotton, silk and flour mills, etc.; technology of electricity, heating and ventilating, construction and operation of steam railways, etc.

In the last year the electrical engineers in common with the mechanical engineers complete the last courses in mechanics, hydraulics, mining, technologies, etc., and make two theses consisting of comprehensive detail drawings of a prime mover and plans of an industrial plant, and follow separately the course of dynamo and transformer design and operation, industrial applications of electricity, theory of electrical measurements and laboratory work.

The total lecture, laboratory, and draughting room work consists of 48 hours a week, 8 hours per day, approximately evenly divided, half for lectures and half for laboratory, draughting, etc. During the last years of instruction, the students under the direction of the professors carry out comprehensive efficiency tests of power plants and other industrial tests, measurements, and surveys, and make frequent visits to industrial plants throughout the country and to expositions, whenever feasible. The school discipline is very strict, and willingness and ability to do intense and sustained work is a requisite for remaining in the Institute. The teaching personnel for the theoretical subjects is made up of regular professors, while for almost all the engineering subjects the personnel consists of engineers, who, besides the educational work, have a large consulting engineering practice. This arrangement has worked out successfully in Milan, the main reason perhaps being the fact that Milan is the largest industrial center of the kingdom.

From his long experience with the polytechnic, Professor Brioschi has found that by an overwhelming majority the most successful careers are made by engineers whose early training and mind discipline had been along lines of broad classical and liberal education rather than those who in their early training had had a preponderance of practical studies like physics, mathematics, and modern languages. These results are rather striking, and, one would almost say, unexpected.

While realizing the difficulties of establishing comparisons and drawing conclusions for conditions vastly different, I do, however, believe that in this moment, when people under the pressure of a strenuous life are clamoring for simplified spelling, practical education, and other short-cut schemes, we owe it to our profession to place our aims at a high level; it is due to the intellectual standards of our leaders and the importance of our work in the community, and we should back up our position with doing all that is in our power to promote and advocate for this country, alongside but distinct from the highly specialized engineering schools, the evolution of a few centers of learning where the most liberal engineering education can be secured by those who by intellect, aspirations, and other favorable circumstances can afford to undergo a broader preparatory work and possibly a longer term at the college.

These centers, by attracting the best talent of the country to their educational staff, would indirectly benefit the other colleges by raising the standard of the whole profession, and would be a nucleus for that free intellectual and scientific activity which is the guiding spirit of the progress of this country.

President Stott: Thinking over this subject and listening to the discussion impels me to emphasize one or two points. The professors have asked us to be specific in criticism. The discussion to-night might be summed up by saying that there is a lack of general education of the freshman entering college. What is that caused by? The smattering of everything he gets in primary and high schools, a little of this and that, nothing taught thoroughly. The remedy for that is for our technical schools to raise the standard of their entrance examinations. If that be done, the other schools will be forced to raise their standards to meet it. The discussion seems to lean distinctly toward the point that engineering schools should teach fundamental principles and not engineering practice. I do not believe degrees should be granted until a man has been out of college for at least five years. In Great Britain doctors do not get their M.D. degree until they have been out of college and practicing for a number of years. I believe no one should receive a degree of mechanical or electrical engineer until he has had the practical training to make him worthy of such a degree. The weeding out process, which is inevitable at some stage, is a very hard problem; there are many reasons, financial and otherwise, why it should be almost impossible for a technical school to weed out students who, whilst qualified as students, are not likely to become engineers. If the degree in engineering were to be conferred only upon proof of work done, say five years after graduation, the stigma of the weeding out process would be taken away from the college; and when a man received his final degree in engineering, it would really mean that he was qualified to state that not only had he the necessary theoretical knowledge, but that he had also survived the refining process which sifts out 50 per cent. of our graduates in the first five years, leaving only those who are likely to become successful engineers.

Chas. P. Steinmetz: It appears to me that the question, how to get a thorough understanding of the fundamental principles, is answered in my paper. Drop out a sufficiently large part of the matter which the college now attempts to teach, so as to find time to improve the quality of the rest by thoroughly teaching it; that is, going over the subject over and over again, approaching it from different view points. After all, a clear and thorough understanding of a subject is gained only by looking at it from every possible point of view. For instance, the induction motor is not understood properly by considering it as a short-circuited armature revolving in a rotating field; it is not understood by considering it as an armature acted upon by a system of quadrature magnetic fields; it is not understood as a derivation of the direct-current shunt motor, combined with the transformer action transferring power to the rotor instead of leading it in by commutator and brushes; nor is it understood by considering it as an electric circuit revolving in an alternating magnetic field. It has to be looked at from all these view points before it can be understood. There is no time for this in the present college course. From my experience with very many college graduates, Americans as well as the product of foreign colleges, from far Russia in the West to Japan and India in the East, I am led to believe that any instruction is useless if it is not kept up to the end of the college course; that whatever the student has studied in one year and then drops, is of little benefit to him. To prove this, last year we gave our electrical engineering students shortly before graduation an examination in mathematics, in those branches which they had concluded in the sophomore year. The results were startling. This year the assistant professor of electrical engineering is giving one hour a week in mathematical subjects, to the junior as well as to the senior classes, with home work in applied mathematics. This has resulted in great improvement in the attitude of the students regarding the value of mathematics to the engineer.

I do not believe in text-books. I agree that a good text-book is better than a poor instructor. To me, a good text-book is merely a way of ameliorating a little the objectionable effect of a poor instructor, but a good instuctor is vastly superior to the best text-book.

It is gratifying to see the almost universal consensus of opinion, that practical familiarity should precede the mathematical theory of engineering, that the instruction should be built up in gradually widening circles through a study of the appearance, the action, the behavior, and the running of apparatus, and then gradually building up to an understanding of its operation, a study of the theory—ultimately culminating the structure with the most general, the mathematical equation and the most specific, the numerical calculation. A further development of this idea, carrying out this principle, is Professor Karapetoff's concentric method. I thoroughly believe in it. But there are difficulties in the way: experience proves that an intelligent and ambitious workman who has become familiar with electrical apparatus by operating it, or working in electrical factories, is anxious to find out the why and wherefore of a machine. Frequently the student is liable to be listless in this respect. When he has gone over the subject in a practical way first, and then goes over the same subject theoretically and more thoroughly, he is liable to neglect it because he thinks he knows enough about it. This means, to introduce better and more modern methods, we must start farther back, with the high school, and beyond the high school. A large part of the defects of the college education are really defects inherited by the college from the high school and the primary school and there is where the lever must be applied to improve conditions. The second serious difficulty is that before we can modernize and improve the education of the college boy we are obliged first to educate the college staff to the realization that conditions are not satisfactory. We are liable there to be met with statements as to what proper pedagogic principles and correct pedagogic methods are, and then we can hardly look for very much co-operation, from men who are satisfied that their way is the only right and proper method.

A. E. Kennelly (by letter): The questions under consideration are in one sense of great antiquity, although from another viewpoint they are of very recent origin. They are of great antiquity in the sense that electrical engineering is only a particular kind of engineering, and engineering is coeval with civilization itself. We have only to examine the pyramids of Ghizeh or a Roman aqueduct to realize that engineers existed thousands of years ago, and that such engineers must have received training for their work in some manner. On the other hand, the subject before us is of very modern growth in the sense that *electrical* engineering has made such recent development. Modern methods of instruction in electrical engineering are therefore the latest evolutions of educational training offered to meet the joint demands of the public, the engineering profession, and the engineering student body.

The Educational Committee can, no doubt, render to the Institute valuable service by collecting and collating information concerning the various systems and details of engineering educational methods adopted in different institutions of this country or abroad. It is, however, earnestly to be hoped that the Educational Committee will not seek to standardize engineering education, in the sense of pressing all institutions to follow as nearly as possible one and the same path, term, and system of engineering training. It is perhaps desirable that one and the same college degree in engineering should represent substantially the same amount of training or attainment on the part of the average student, so that it may be proper to attempt standardization in regard to the grading of one and the same degree. It seems undesirable, however, that all colleges or institutions training youths in engineering should grant precisely the same degree, or should offer identically the same training, should receive the same material, or should attempt to turn out the same finished product. It is here contended that what is more desirable is a wholesome diversity of aims, conditions, and training.

We know that in the world of mental activity as well as in the world of physical activity, achievement does not depend wholly upon training; it depends upon inheritance as modified by training. No great athlete, great singer, great engineer, or great worker of any kind was ever produced by training alone. We have the experience of mankind in all historical time to attest this fact. Men are born with an infinite range of capability for achievement in any given division of human affairs; some become eminent without any school or college training; while a great number can never become capable, no matter how much training they receive. All that we know is that training and education will increase each individual's power and capability, whatever that may be. An education is, therefore, an investment on the part of a student in time, money, vitality, and effort, for training to assist his inherited capabilities in his chosen life's work. It seems to be a biological law that the greater the inherent power of an organism, the longer the time and training required to bring this power to its greatest development. The highest types of mankind take the longest training with advantage. It does not pay to train the moderately gifted lengthily and extensively; it does pay to train the highly gifted long and thoroughly. The great bulk of the world's work must be done, and should be done by average men, and where there is room for one leader or colonel of a regiment, there is room and opportunity for creditable work to be performed by hundreds of average men. What is needed, therefore, is not that all institutions should attempt to turn out exactly the same type of graduates in engineering; they cannot, even though they try. Education should be graded to suit the needs of different individuals. We need many more privates and non-commissioned officers in engineering and industrial work than superior officers; and the country can be better served as a whole by offering a greater diversity of periods and types of engineering training. In addition to correspondence schools and evening schools, there is need of the training which can be offered by schools with schedules lasting from three months to six years. Such diverse trainings should be co-operative, in such a manner that a student entering upon a short course and showing ability to receive a longer and more thorough training should be aided in effecting a transfer; and, conversely, a student attempting too long a training should be aided in saving his time and energy by transferring to a shorter course. None of these different schedules would necessarily be superior or more worthy than another; they would all be equally important to the community as a whole.

H. B. Coho (by letter): We all know that fully 50 per cent. of the graduates from our technical schools and colleges receive their degree, not by any very brilliant actions or effort on their own part, but by the grace of their alma mater. These degrees are, therefore, heavily discounted, and their value is problematical. The average boy goes to college because it is an eminently respectable thing to do; he acquires a social standing, and an acquaintance, the value of which is well known. He enters the institution often on a diploma from a high school or preparatory school, which certifies that he has had a certain amount of opportunity to study a given quantity of subjects, and ought to know something of them.

To my mind the degree of a technical school ought to mean something absolutely, or else it should not be given; and I am firmly convinced that the degree of electrical engineer should be conferred by the American Institute on such of their members as can pass a given examination, and show at least three years' practical experience in the line of their chosen profession; this degree should be open to the artisan as well as to the college-bred man that can qualify.

My opinion is that the remuneration of college professors has comparatively little to do with the results, as I doubt very much whether our captains of industry would make good teachers, and, *vice versa*, whether our teachers would make satisfactory captains of industry. To make a success of anything, a man must devote his time and thought to the subject in hand, without heeding the money recompense. The mere lust for money is easily satisfied, but the lust for power and achievement cease only at death.

Before a piece of steel can be sharpened it must be tempered; so with the human mind, the mind must be trained before it is ready to receive the finer impressions.

As Dr. Steinmetz has said, then, the improving of the lower grades must be carefully attended to, The boy is the father to the man, and we all know that it is impossible to obliterate entirely impressions received during the first ten years of life, therefore, the importance of giving care and attention to the primary and secondary grades in our public schools is apparent.

To my mind, our school system should be so devised as to give a pupil from the beginning individual attention, treating him as a unit, and not as a class, and keeping a careful record of his work throughout his whole school life, so that when he reaches the age where a selection of occupation is to be made he can be advised and guided. By making his entrance to college or technical school dependent not only upon his ability to answer a certain list of questions, but also on his record, we shall greatly improve upon the material which our teachers will have to deal with; the product of our educational institutions will then be men, capable of taking up life's problems in an intelligent manner.

A. S. McAllister (by letter): The fact that a large percentage of the graduates from engineering colleges prove unsuited for engineering work, as stated by a speaker who is exceptionally well qualified to make observations, is one that has as yet not received the proper amount of consideration from those interested in the education of our boys. The present writer believes that the college courses and methods of instruction furnish only a small part of the cause for the result. During my short teaching experience, I became thoroughly convinced that many of the students that came under my observation were much better qualified for some line of study different from engineering rather than for engineering itself. The fact that a student makes indifferent progress in engineering does not prove either that he is lacking in brain matter or that the method of engineering instruction is incorrect; in many cases his parents or the advisers of the student during his high-school days are at fault. It is absolute folly to attempt to make an engineer out of a student who during his high-school days shows not only no taste for physics and mathematics but is innately averse to all studies that appeal to the reason rather than to the memory. There are students who display no marked inclinations along any certain line of study, while there are others who seem to enjoy all lines. The latter, however, are the exception rather than the rule. A fact that should always be kept in mind by those in position to decide whether certain boys shall attempt engineering college work or take up other duties immediately after leaving high school is that a college can develop latent talents but that it cannot put brains into an empty skull; it cannot make an engineer out of a boy whom nature has deprived of well arranged reasoning faculties. It would obviously be very improper for anyone to claim that an engineer, like a poet, is born and not made. However, it can be truly stated that the chances for success are infinitely greater for that boy who selects a career in conformity with his natural talents, than for one who adopts a profession merely because his parents consider it one in which the average compensation is comparatively high. Many of the third-rate lawyers and doctors of the present day could have made excellent engineers; many of the present day inefficient engineers could have become first-class doctors or lawyers. It is an absolute injustice to the student to allow him to undertake one line of work for which he has no talents, and thereby permit his natural talents which lie along other lines to remain dormant. The entrance requirements should be arranged in such a way as to determine for what line of work a boy is best suited, in order that he may secure the maximum good from the time spent in college, and the instructors may obtain the best results from their labors.

W. S. Franklin (by letter): My hobby is mental arithmetic. The ability of a student to follow a simple physical argument depends vitally upon his power to hold numerical relations in mind, and the greatest difficulty that I encounter in my work of teaching elementary physics arises from lack of this kind of arithmetical sense on the part of the student. For many years I have tested my junior students with the question: "When does a growing thing reach its greatest size?" I have found but one student in all my experience who was ready with the simple arithmetical answer: "When it stops growing". And yet nearly every man in every class could have filled a blackboard with algebraic formulas in response to a formal question concerning the maxima and minima of an algebraic function.

In discussing the ballistic galvanometer, one arrives at the proposition that the rate at which the suspended needle gains angular velocity is proportional to the rate at which charge flows through the coils, from which one argues that the total angular velocity gained is proportional to the total discharge. I always illustrate this point by asking the class to consider one man who saves money ten times as fast as another, whence it may be argued that the one man must always have ten times as much money as the other, if they get an even start, and then I ask the class what this argument is called, but never yet have I found a single student who had a sufficiently simple idea of calculus to know that this arithmetical argument is called integration.

I have always had a desire to use the algebraic forms of calculus in my teaching of elementary physics, but the weakness of most students in the simpler branches of mathematics and the almost universal lack of arithmetical sense (the holding of numerical relations in mind) has forced me to the conclusion that it is ridiculous at the present time for any teacher to attempt to use calculus in the handling of any subject in the class-room. I think it is no exaggeration to say that ninety-nine per cent. of the technical graduates with whom I have conversed have admitted their total lack of understanding of the subject of calculus when they took it in the technical school. If most of us did not stand in awe of mathematics, such a state of affairs would lead us instantly to the conclusion that something was radically wrong, but it seems that most men are still imbued with the idea expressed many years ago by the great English mathematician, Sylvester. Sylvester showed an unusual aptitude for mathematics while still an undergraduate, and he said that he was pointed out by his mates as a man who, like Dante, had seen Hell, the idea being that mathematics was not supposed to be understood by the great mass of students who were required to study it. Now I contend that calculus must be understood by the great majority of men who study it, or it must cease to be taught; and I believe that the reduction of calculus teaching to the plane of old-fashioned mental arithmetic would go a great way towards meeting this situation.

O. J. Ferguson (by letter): A man goes to college to save time by concentration. All that he acquires there can be obtained elsewhere and by other methods, but the operation of these other methods is subject to so many interruptions and diversions that the efficiency rate at which the work is done is low.

No college training of a few years can fit a man to occupy positions of great engineering responsibilities. It must be augmented by experience. During college life he is considering the available results of experience of others, but man is so constituted that he must learn ultimately by his own personal contact with facts.

Of these two components of his training we are discussing the one which comes under the direction of instructors. The most important things to be considered therewith are, in the broadest sense:

1. Methods of thought.
2. Fundamental truths.
3. Allied subjects.
4. Average data.
5. Experience—enough to serve as illustrations and as "labels" for theory.

No engineer who comes into contact with men recently graduated from colleges can fail to note the general inability of their minds to grasp important details, sift, summarize, reason logically, and analyze keenly. All minds are not equally endowed in these respects, but training should bring out whatever exists of these all-important requisites to the engineer.

Mathematics is the purest of logical and analytical reasoning, and, considered even wholly aside from its utility, should be placed in the first years of college work and never wholly omitted later in the course. Its value lies in the fact that it permits clear, concise, definite statements, and demands proof of every step from its " Given " to its " Q. E. D." It should progress from the pure to the applied, and to broad engineering practice which is richer in problems than is the mind of any author of mathematical text-books.

Facts are of several kinds: Truths, facts of to-day, facts of yesterday, and things that never were so. Fundamental truths should be distinguished from current practice. Keep up with the times but do not lead students to accept offhand the things of to-day as the standards of to-morrow. One can devote too much time to practice to obtain breadth of view.

Allied subjects should be taught, not from the electrical engineer's view, but broadly and carefully though not in detail from the point of view of the specialist. For, no matter what we are using or are not using now, the future will demand more from us.

Average data of existing normal practice should be analyzed for fundamentals. Machine shop and laboratory work are beneficial so far as they serve to clarify ideas of machinery, circuits, and power development, transformation and measurement, and to illustrate methods of reasoning in the study of problems. As before indicated, they are the pictured labels attached to carefully stored bits of information and are to be used as identification marks in selecting such data for comparison with subsequent experience. A great deal of the time spent in manual training, etc., is of little value compared with what might be accomplished by a better use of the same time. Personal experience should not be allowed to intrude itself into any curriculum at the expense of concentration upon the main line of thought.

As for the order in which certain studies are met, I believe it is better to prepare the broad foundation first with its tendencies toward habits of scientific reasoning and research—painstaking and deliberate. Theory can at first be stripped of its "negligible quantities" and is still intricate enough for the beginner. Practice can never eliminate these minor influences which serve to hide to a greater or lesser degree the principles sought, although they may not seriously influence the problem at hand.

C. O. Mailloux (by letter): The lecture system is objectionable, in my opinion, so far as, and to the extent that, it robs a student of the time and the energy requisite to study his notes properly, because too much time and energy have to be consumed in taking the notes and, especially, in correcting, rearranging, completing or rewriting them; in a word, in making them "fit" to study. A certain amount of "going over" the notes, on the part of the student, is, in my opinion, desirable; but much of its beneficial effect is lost when the notes are incomplete and incorrect because the student was not able to follow the lecturer. Unfortunately, this occurs much more often than ought to be the case. It is for this reason that the syllabus and book of reference becomes valuable, if not indispensable, as a means for filling the gaps and voids, and of mending lame notes containing incomplete or incorrect diagrams, formulas, etc. It does seem as if much of the student's time and energy, that now has to be devoted to correcting and amplifying his notes, might be devoted to studying them. After observing and studying carefully the methods of some forty or more lecturers on technical subjects, from the dual standpoint of student and teacher, I am of the opinion that the shortcomings of the lecture-system of instruction are more often due to the lecturer than to the lecture-system; and that it would be only necessary, in many cases, to improve the method of the lecturer, in order to improve the results of the system. The ideal system, in my opinion, is a lecture-system, in which the lecturer, either by dictation or by writing out in sufficient detail on the blackboard, or by means of a good syllabus, simplifies the student's task of getting accurate notes, and, at the same time, allows him time to follow the reasoning, demonstrations, and discussions presented. It is too often the case that the student is so busy with the mechanical work of taking down notes, that he is totally unable to follow, much less to absorb and digest, the subject-matter presented. In such cases, it is obvious that the method of teaching by lectures is much inferior to that of teaching by the text-book system. As already stated, however, the fault lies more with the particular method of the lecturer than with the lecture-system.

H. W. Blake (by letter): On one point all engineers are agreed, namely, that it is impossible to crowd into a four-years' course all of the instruction which the young electrical engineer will find useful after graduation. If this is true at the present time, it is evident that as the art advances year by year it will be necessary still further to circumscribe the number of subjects included in the required courses. This will involve yearly additional sacrifice of instruction in those branches, which are classed by one speaker as "cultural and scientific" rather than purely technical.

The engineering schools are now attracting many men whose fields of activity after graduation are almost as varied as those of the graduates in the academic or arts department. These men would formerly have matriculated in the older college course, but the inclusion into so many lines of industry now of engineering principles makes an engineering education a desideratum. At the same time, a knowledge of the purely technical branches of the subject is not so important for many of these students as a good acquaintance with such topics as business-law, rhetoric, and modern languages, and the ability to meet the political and economic questions which are apt to arise in the administration of engineering undertakings.

The technical educator is, then, face to face with a serious dilemma. Should he confine his curriculum to the purely technical studies which experience has shown require the entire time of the undergraduate to master, or should he subordinate some of them to those cultural and scientific branches desired by a large number of men entering the technical schools yearly? The answer to this question is really dependent upon a decision whether it is possible to introduce electives in an engineering school to the same or nearly the same extent as in the arts course. One reason advanced for not following this plan is the expense of supplying the varied instruction, but this hardly applies in universities, where these outside courses are taught in other departments. Another objection has been the question of degree, because the title of engineer, civil, mechanical, or electrical, awarded at the end of the course, is generally considered to imply familiarity with certain prescribed studies. This objection may be valid and may not. Certainly, however, the tradition is not as venerable as that which limited the degree of B.A. to a college course which should include at least two years of study in Latin and Greek. This requirement is no longer in force in many leading universities. If necessary, the engineer's degree could be reserved for a post-graduate course along certain well-defined lines. The chief point is that the electrical engineering industry is now calling for many men whose training should primarily be along engineering lines, but who also require certain instruction which the technical schools cannot give unless they incorporate into their curricula a liberal system of electives.

Dugald C. Jackson (by letter): Many excellent words are said in the two brief papers which have been presented by Mr. Scott and Dr. Steinmetz, but I am compelled to take the view that neither of the papers makes any constructive suggestions which may lead to an advance in engineering education. Perhaps the nearest suggestion that comes to that point is to be found on the first page of Dr. Steinmetz's paper, where he refers to the importance of close coöperation between the electrical industries and the engineering colleges. That coöperation is growing up rapidly as a matter of necessity, but it has heretofore been more or less undirected, and I had hoped that the papers of this evening would give us some suggestions for making more out of that effort. This is surely an important question for the Educational Committee carefully to consider and digest with a view of bringing up concrete and constructive proposals. Dr. Steinmetz makes the interesting statement that the existing coöperation probably constitutes the strongest feature of American engineering education. I am in partial agreement with him, but I am by no means in agreement with what I understand to be his implication that the present coöperation is as effective or intimate as it should be. I will not here undertake to enter into the enumeration of the reasons for my views, but will perhaps undertake to do so at some later date.

In this connection I wish to call attention to Mr. Scott's statement that a fairly intimate intermingling of college work with practical work will be found to conduce to the efficiency of each, and I wish to express my hearty sympathy with that statement. I believe that much can be done in the way of improving our present electrical engineering education by increasing and strengthening the kind of coöperation which is suggested in this sentence of Mr. Scott's.

Mr. Scott's paper seems to indicate that he stands for Professor Karapetoff's plan, which has been dubbed the " concentric method ", but I am sure that Mr. Scott could not be the unqualified supporter of that plan had he submitted Professor Karapetoff's proposals to a detailed analysis. The plan which has been presented under the name of the " concentric method " is one which naturally catches the attention of a busy industrialist, and it may hold his attention until the conditions of his industrial work will give him leisure to analyze carefully the processes described. Then he will find that the details proposed by Professor Karapatoff are subject to serious criticism as being in opposition to the basal tenets of pedagogy; though the general plan does not differ very much from the plan which is in operation, with marked success, in several of the best engineering schools. Given time on my part and leisure on the part of Mr. Scott, I will undertake to convert him to my view on this matter, with the understanding that that conversion will be permanent because it will be based upon sound reasoning.

The defects which Dr. Steinmetz points out in the second page of his paper will be admitted by thoughtful and experienced teachers of engineering, but it is happily a fact that these defects are being slowly cleared away. The rate of improvement is so slow as to be exceedingly discouraging when considered year by year, but the aggregate improvement which has been made in the past decade is so marked as to give good ground for optimism in respect to this part of engineering education.

In this connection I wish to point out that Dr. Steinmetz seems to possess a misapprehension in respect to the ideals of some of the better engineering schools. It cannot be properly said that the students in all of the engineering schools are allowed the opportunity to take up the important basal subjects and are then intentionally allowed to drop them without succeeding drill in their applications. The fact is that the mathematics, the chemistry, the physics, the applied mechanics, and the more distinctly professional studies following thereafter should be closely correlated and dovetailed into each other, the order of the work being planned with due consideration of the coördination of the subjects; and care is taken to effect this coördination in certain of the engineering schools. Dr. Steinmetz is probably right in criticizing the arrangement of most electrical engineering courses from this point of view; but, unquestionably, the ideals lying behind the teaching in several of the electrical engineering courses give due and full consideration to these factors; and, indeed, no course can be carried on with fair consideration of the best known principles of pedagogy without including provisions for these factors. The worst features of many of our engineering courses have arisen from the fact that so much of their work has been introduced without consideration of the pedagogical sequence of the parts or the relation of each part to the whole.

Mr. Scott ventures the prediction that the solution (which will find the most general acceptance) of the problem of what is the best engineering education, will be that which gives to each student the training that fits him for his best individual development. In these words Mr. Scott has stated an important principle in education, and he is to be heartily thanked for putting the matter so plainly. To get a fundamental principle clearly in mind is often half the battle. But Mr. Scott leaves us still groping, because he gives no adequate indication of the direction in which engineering courses may be improved for the purpose of gaining the goal which the principle lays down. The same may be substantially said of Dr. Steinmetz's paper. Dr. Steinmetz remarks that the present condition in the industries, wherein men who have never had a college education may rise ahead of college graduates, would be impossible if our engineering courses gave what they should, namely, an intelligent understanding of electrical engineering subjects. But the difficulty under which we now labor is to lay our finger on the specific improvements which can be and should be effected for the purpose of affording this intelligent understanding of electrical engineering subjects that Dr. Steinmetz asks for. What the engineering schools need now is careful analytical scrutiny of their processes of work, and constructive suggestions for changes which will bring about improved results.

I believe that the better engineering schools have a lively understanding of their defects, and a well-developed desire to overcome them, but a difficulty resides in determining what improvements will bring the wished for results. Experiments in education generally require years of trial before their effects can be clearly discerned, and experiments must therefore be made with caution to prevent taking any backward step.

I wish to say a word in regard to the remarks of two or three other members who entered into this discussion. In respect to Mr. Ferguson's remarks, I believe that I can say that I heartily agree with the whole of his presentation; and I also want to express my appreciation of Professor Clifford's admirable presentation of the requirements in engineering education. I would like to emphasize, more than Professor Clifford's remarks emphasized, the necessity of adding those things which lead to the education of judgment; and my acquaintance with Professor Clifford assures me that he probably agrees with me on this point.

Mr. Stillwell directs attention to the proposal that the ideal education for engineers is going to be brought about by the plan which is now being shouted as a shibboleth from the housetops—an arts course first and an engineering course afterward. I do not believe that this is a solution of the difficulties which are outlined in the papers of the evening, and I believe the plan was originally conceived by men who are unacquainted with the necessities of engineering education. These men may have a profound knowledge of the great results that come from a proper pursuance of the old-time arts course, but this does not give them the experience or the power which makes them sound leaders in the problem of engineering education. I believe it is a misfortune that such admirable engineers as Mr. Stillwell are willing to lend themselves to the promulgation of this plan without a full and complete analysis of its results. I heartily agree that an engineer needs to be a broadly and completely educated man; but where two horses are to be driven it is better to drive them side by side (in parallel) rather than in tandem, if one aims at effective power and not merely at showy results. It seems to me that the engineering course, to be fully effective, should include the physics and the chemistry and the mathematics and much of the general studies in the engineering school, and subjects such as political economy, history, and the languages may be appropriately carried out to the end of the course. This, indeed, is a factor which I understand Dr. Steinmetz approves, and it is this suggestion contained within the so-called "concentric method" which I presume attracts Mr. Scott's friendly attention. The failure of the concentric method lies distinctly in the repetitions of work which it recommends. There may be a real utility in the modified proposition which is now beginning to gain vogue amongst the best thinking men of the engineering schools, and also of the literary and classical colleges, which proposes that students shall spend perhaps two years under the influences of the arts course and shall then spend four years under the conditions of the engineering school. This would make the engineering school base its entrance requirements upon attainments gained by the students from two years of the arts course in college or university, and the plan comprises many factors which indicate its utility as an educational plan. The plan urged by Mr. Stillwell calls for three or four years in the arts course and then for two or three years in the engineering school; but this abbreviates the engineering course to a degree which makes the joint work relatively ineffective, besides giving the students a misapprehension of the relative importance of their historical and literary studies compared with their technical studies (by substantially dismissing the former from their attention for several years while the technical studies are being pursued) and leading them to the erroneous belief that the humanistic studies do not belong to their lives as engineers.

A paper presented at a meeting of the Philadelphia Section of the American Institute of Electrical Engineers, Philadelphia Pa., February 10, 1908.

THE SINGLE-PHASE COMMUTATOR-TYPE MOTOR

BY B. G. LAMME

The broad statement may be made that it is no more difficult to commutate an alternating current than an equal direct current. Such a statement would appear to be entirely contrary to the usual experience, but a little study of the matter will show where the apparent discrepancy lies. In commutator type alternating-current motors, as usually built, a relatively large number of commutator bars pass off under the brush during one alternation of the supply current. While the current supplied is varying from zero to maximum value and back to zero, possibly 50 bars have been passed under the brush, and therefore 50 coils in the armature have been reversed or commutated. Some of these reversals occur at the top of the current wave which has a value of about 40% higher than the mean or effective value which is read by the ammeter. The motor is therefore at times commutating 40% higher current than that indicated by the instruments. It is thus evident that in comparing the commutation of 100 amperes direct-current with 100 amperes alternating-current we should actually compare the direct-current with 141 amperes alternating. In other words, for commutating equal currents alternating-current or direct-current, the alternating-current ammeter should register only 71% as much current as the direct-current. Another way of expressing it is that we have to commutate the top or maximum of the alternating-current wave, while our instruments only record the mean value.

If the above represented the only difference between the alternating current and direct current the problem to be solved in commutation of alternating current would not be serious.

However, the current to be commutated by an alternating-current motor is not merely the working current supplied to the motor and measured by the ammeter, but there is, in addition, a current which is generated in the motor itself, both at standstill and during rotation, which has to be reversed or commutated along with the working current. It is this latter current, usually called the local or short-circuit current, which has been the source of greatest trouble in commutating alternating current; for this short-circuit current may have a value anywhere from three to ten times the working current, depending on the design of the machine. Therefore in comparing the commutation of an alternating current, as indicated by an ammeter.

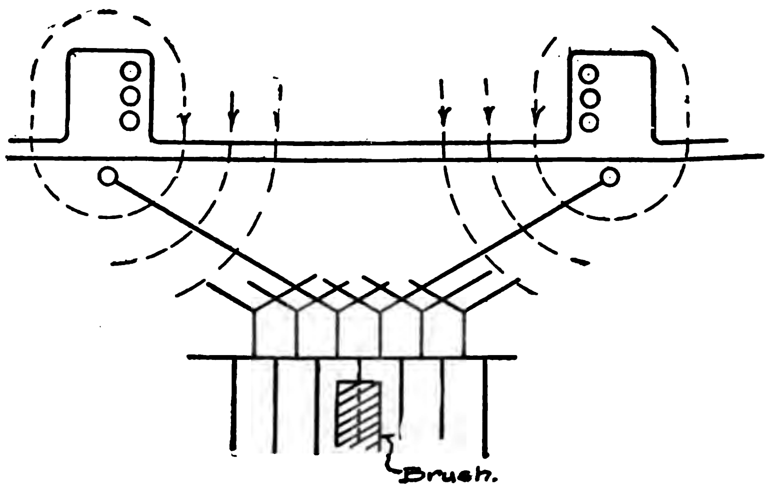


FIG. 1

with an equal direct current, we should, in reality, consider that the alternating-current motor is commutating a maximum current from five to ten times the value of the indicated current. Furthermore, it would not do to reduce the ammeter current to one-fifth or one-tenth value in order to compare commutation with direct current, because by so doing we would simply be reducing the small applied component of the total current commutated by the brushes, the local or short-circuit current still retaining a rather high value. In order to compare with direct-current commutation, it would be necessary for the total maximum of the combined supply and the short-circuit current to be reduced to the same value as direct current.

It is the local current in the armature turn short-circuited by the brush which is the source of practically all the trouble in commutating alternating currents. Fig. 1 illustrates a portion of the field and armature structure of a commutator type alternating-current motor. It will be noted that the armature conductor, which is in the neutral position between poles, surrounds the magnetic flux from the field pole, just as the field turns themselves surround it. The field flux being alternating, this armature turn will have set up in it an electromotive force of the same value as one of the field turns. Short-circuiting the two ends of this armature turn should have the same effect as short-circuiting one of the field turns, which is the same thing as short-circuiting a turn on a transformer. Such a short-circuited turn, if of sufficiently low resistance, should have as many ampere-turns set up in it as there are field ampere-turns. In single-phase motors of good design the field ampere-turns per pole are about twelve to fifteen times the normal ampere-turns in any one armature coil. Therefore, if the armature coil in the position shown in this Fig. 1 should have its ends closed on themselves the current in this coil would rise to a value of twelve to fifteen times normal. In reality, it would not rise quite this much, because this armature turn is placed on a separate core from the field or magnetizing turns with an air-gap between, so that the magnetic leakage between the primary (or field winding) and this armature (or secondary winding) would tend to protect this coil somewhat, just as leakage between the primary and secondary windings of a transformer tends to reduce the secondary electromotive force and current. Also, this armature coil is embedded in slots, thus adding somewhat to its self-induction, and tending further to reduce the short-circuit current. In consequence, with its ends closed together the current in this armature coil would probably not rise more than ten to twelve times above normal value under any condition. It is evident, therefore, that if the brush shown in Fig. 1 as bridging across two commutator bars to which the ends of this coil are connected is of copper or other low-resistance material, then there could be an enormous local current set up in the coil when thus short-circuited by the brush. This local current of about ten times the normal working current would have to be commutated as the brush moves from bar to bar, and therefore the operation of the machine would be similar to that of a direct-current motor if overloaded about ten times in current. In other words, there would be vicious sparking.

Even if the low-resistance brush were replaced by one of ordinary carbon, the short-circuiting current would still be relatively high, due to the fact that it is not possible to make the brush contact of very high resistance by reducing the size or number of the brushes, because these same brushes must carry the working current supplied to the motor, and there must be brush capacity sufficient to handle this current. This brush capacity will, in practice, be of such amount that the resistance in bridging from one bar to the next is still rather low, although much higher than if a copper brush were used. Experience shows that with not more than four or five volts generated in this short-circuited coil by the field flux, the resistance of the carbons at the contact with the commutator would be such that a short-circuit current of three to four times the normal working current in the coil can still flow. Therefore, if the motor were equipped with carbon brushes and had but four or five volts generated in the short-circuit coil, the motor would have to commutate the main or working current and also a short-circuit current of possibly three times the amount. This short-circuit current would also have a maximum or top of its current wave Assuming 100 amperes as the current supplied to the motor, the machine therefore actually commutates a supply current of 141 amperes and an additional short-circuit current of possibly three times this value, or from 400 to 500 amperes, therefore, the motor actually commutates the equivalent of about 600 amperes direct current when the alternating-current ammeter is reading 100. It is evident from this that any one who tries to commutate alternating current with an ordinary type of commutating machine would at once draw the conclusion that alternating current in itself is very difficult to commutate, naturally overlooking the fact that it is the excessive current handled by the brush that is back of the trouble, and not the current indicated by the ammeter.

From what has been stated, it is evident that the excessive local current is back of the difficulty in commutating alternating current. All efforts of designers of alternating-current commutator motors have been in the direction of reducing or eliminating this local current. The present success of the motor, in the various forms brought out, is largely due to the fact that this current has been successfully reduced to so low a value that it does not materially add to the difficulties of commutating the main current. No successful method has yet been practically developed for entirely overcoming the effects of this short-circuit current under all conditions from standstill to highest speed. Some of the corrective methods developed almost eliminate this current at a certain speed or speeds, but have little or no corrective effect under other conditions; other methods do not effect a complete correction at any speed, but have a relatively good effect at all speeds and under all conditions. The former methods would appear to be applicable to motors which run at, or near, a certain speed for a large part of the time; the latter method would be more applicable to those cases where the motor is liable to be operated for considerable periods with practically any speed from standstill to the highest. While several methods have been brought forward for correcting local current when the motor has obtained speed, yet up to the present time but one successful method has been developed for materially reducing this current at standstill or very low speeds. It may be suggested that the short-circuit voltage per coil be reduced to so low a value, say four or five volts, that the local current is not excessive and does not produce undue sparking. This would certainly reduce the sparking difficulty, but is open to the very great objection that the capacity of the motor is directly affected by a reduction in the short-circuit voltage. This voltage per turn in the armature coil is a direct function of the value of the alternating field-flux and its frequency. Assuming a given frequency, then the short-circuit voltage is a direct function of the induction per field pole, and the lower the short-circuit voltage the lower must be the field flux. But the output of the machine, or the torque with a given speed, is proportional to the product of the field flux per pole by the armature ampere-turns. In a given size of armature the maximum permissible number of ampere-turns is pretty well fixed by mechanical and heating considerations, and therefore with a given armature the torque of the motor is a direct function of the field flux. Using the maximum permissible armature ampere-turns, the output of a given motor would be very low if the field flux were so low that the short-circuit voltage would not be more than three or four volts. Increasing the field induction, and therefore increasing the short-circuit voltage, increases the output.

Experience shows that on large motors, such as required for railway work, the induction per pole must necessarily be so high that the electromotive force in the short-circuit coil must be about double the figure just given; therefore, with such heavy flux the short-circuited current will necessarily be excessive unless some corrective means is used for reducing it.

I will consider the standstill or low-speed conditions first. For this condition only one practical arrangement has so far been suggested for reducing the local current to a reasonably low value compared with the working current. This method involves the use of preventive leads, or, as they are sometimes called, resistance leads. These consist of resistances connected between the commutator bars and the armature conductors. Fig. 2 illustrates the arrangement. The armature is wound like a direct-current machine, except that the end of one armature coil is connected directly to the beginning of the next

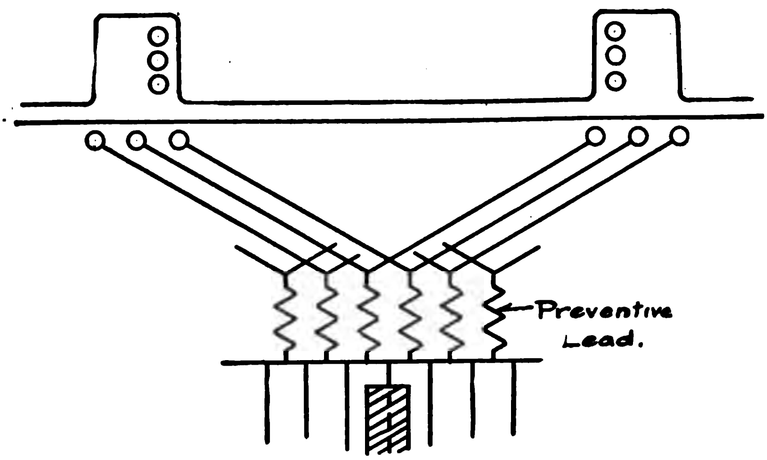


FIG. 2

without being placed in the commutator. Between these connections separate leads are carried to the commutator bars, and in these leads sufficient resistance is placed to cut down the short-circuit current. The arrangement is very similar in effect to the preventive coils used in connection with step-by-step voltage regulators which have been in use for many years. In passing from one step to the next on such regulators, it is common practice to introduce a preventive coil or resistance in such a way that the two contact bars are bridged only through this preventive device.

In an armature winding arranged in this way, the working current is introduced through the brushes and the leads to the armature winding proper. After entering the winding, the current does not pass through the resistance leads because the connections between coils are made beyond these leads. In consequence, only a very small number of these leads are in circuit at any one time; when the armature is in motion all the leads carry current in turn so that the average loss in any one lead is very small. As the brush generally bridges across two or more commutator bars, there is usually more than one lead in circuit, but generally not more than three. When the brush is bridging across two bars, there is not only the working current passing into the two leads connected to these two bars, but there is the local current, before described, which passes in through one lead, through an armature turn, then back through the next lead to the brush. There are losses in these two leads due to these two currents. By increasing the resistance, the loss due to the working current is increased, but at the same time the short-circuit current is decreased. As the loss due to this latter is equal to the square of the current multiplied by the resistance, it is evident that increasing this resistance will cut down the loss due to the local current in direct proportion as the resistance is increased. When the working current is much smaller in value than the short-circuit current, an increase in the resistance of the leads does not increase the loss due to the working current as much as it decreases the loss due to the short-circuit current. Both theory and practice show that when the resistance in the leads is so proportioned that the short-circuit current in the coil is equal to the normal working current, the total losses are a minimum. Calculation, as well as experience, indicates that a variation of 20% to 30% at either side of this theoretically best resistance gives but a very slight increase in loss, so there is considerable flexibility in the adjustment of this resistance. The resistance of the brush contacts and of the coil itself must be included with the resistance of the leads in determining the best value. In practice it is found that with ordinary medium-resistance brushes, the resistance in the leads themselves should be about four or five times as great as the resistance in the brush contact and the coil; that is, we usually calculate the total necessary resistance required and then place about 70% or 80% of it in the leads themselves. When leads of the proper proportion are added to the motor, it is found that practically twice as high field flux can be used as before with the same sparking and burning tendency as when the lower flux is used without such leads. But even with six to eight volts per commutator bar as a limit, we are greatly handicapped in the design of the motors, especially when the frequency is taken into account. This limited voltage between bars also indicates at once why single-phase railway motors are wound for such relatively low armature voltages. Direct-current railway motors commonly use from 12 to 20 volts per commutator bar, or from 2 to 2.5 times the usual practice on alternating-current motors. With this low voltage between bars in alternating-current machines, with the largest practicable number of bars, the armature voltages become 200 to 250, or about 40% of the usual direct voltages. The choice of low voltage should, therefore, not be considered as simply a whim of the designers; it is a necessity which they would gladly avoid if possible.

Assuming preventive leads of the best proportions, let us again compare the current to be commutated in an alternating-current motor with that of the direct-current. Considering the ammeter reading as 100, the working alternating current has a maximum value of 140 and in addition there is a short-circuit current of same value. Even under this best condition, the alternating-current motor must commutate a current several times as large as in the corresponding direct-current motor. The design of such a motor, therefore, is a rather difficult problem, even under the best conditions.

While resistance leads theoretically appear to give the most satisfactory method for obtaining good starting and slow-speed running conditions, yet other methods have been proposed. The only one of any practical importance is that in which the short-circuit voltage is reduced at start and at slow speed by sufficiently reducing the field induction. As this reduced field induction would give a proportionately reduced torque, it is necessary at the same time to increase the armature ampere-turns a corresponding amount above normal. This is only a part solution of the problem, however, for the decrease in short-circuit current by this means is partly offset by the increase in the working current, so that the total current to be commutated is not reduced in proportion to the field flux. Where the period of starting and slow running is very short, this method is fairly successful in practice. However, with this arrangement it is rather dangerous to hold the motor at standstill for any appreciable length of time, for in such a case the large short-circuit current is confined to a single coil and the effect is liable to be disastrous if continued for more than a very short period. With this method of starting, the total current handled by the brushes will usually be at least two to three times as great as when preventive leads are used.

The preceding statements refer mainly to starting or slow-speed conditions. When it comes to full-speed conditions, however, there are various ways of taking care of the commutation. One of these methods is based on the use of preventive leads, as described; the other methods depend upon the use of commutating poles or commutating fields in one form or another.

It is evident, from what has been said, that at start the preventive leads which reduce the short-circuit current to low values will also be effective in a similar manner when running at normal speed. Such a motor with proper proportion of leads will, in general, commutate very well at full speed when the starting conditions have been suitably taken care of. Nothing further need be said of this method except that the tests show that the short-circuit current has considerably less value at high speed than at start.

The other methods of commutation at speed, involving commutating poles and commutating fields, necessarily depend upon the armature rotation for setting up a suitable electromotive force in the short-circuit coil to oppose the flow of the short-circuit current. As the electromotive force in the short-circuited coil is a direct function of the field flux, and is independent of speed, while the correcting electromotive force is a function of the armature speed, it is evident that either the commutating pole can produce the proper correction only at one particular speed, or the strength of this commutating pole must be varied as some function of the speed. Usually the strength of these poles is made adjustable with a limited number of adjustments and approximate compensation only is obtained on the average. In the Siemens-Schuckert motor the commutating poles are of small size and placed between the main poles. These are for the purpose of obtaining commutation when running. In addition the armature is provided with preventive leads for improving the operation at start and at slow speed. In the Alexanderson motor, according to published description, no separate commutating poles are provided, but the edges of the main poles are used as commutating poles, the armature coil having its throw shortened until its two sides come under the edges of the main poles. In this motor the field is weakened and the armature ampere-turns are increased while starting. The commutating-pole scheme in this motor is, in some ways, not as economical as in the Siemens-Schuckert arrangement, as the motor requires a somewhat higher magnetization with a consequent reduction in power-factor. The Winter-Eichberg motor is quite different in arrangement from any of those which I have mentioned. I will not attempt to describe this motor in full, but will say that it has two sets of brushes in the armature, one of which is short-circuited on itself, and carries the equivalent of the working current in the types I have described, while the other carries the magnetizing or exciting current which is supplied to the armature winding instead of the field. The arrangement is such as to give practically the same effect as a commutating pole or commutating field. When starting, the field flux is decreased and the armature ampere-turns increased.

All of the above motors are nominally of low armature voltage and all of them appear to commutate reasonably well at speed. Two of them use the full-speed induction at start, while the other two use reduced induction and increased armature ampere-turns at start.

There has been considerable discussion during the last year or two regarding the most suitable frequency for single-phase commutator type motors. It may therefore be of interest to consider what effect reduction in frequency would have on the commutation, output, and other characteristics of the motor.

The short-circuit voltage, as I have stated before, is a function of the amount of field flux and of the frequency. For a given short-circuit voltage the induction per pole can be increased directly as the frequency is decreased. If a certain maximum induction per pole is permissible at 25 cycles, then with 12.5 cycles, for example, the induction per pole may be double, with the same short-circuit voltage. This would at once permit double output if the saturation of the magnetic circuit would permit the doubling of the induction. But on 25-cycle motors, as usually built, we work the magnetic flux up to a point just on the verge of saturation, so to speak, as indicated in Fig. 3. It is evident that double induction, under such conditions, would not be practicable unless the 25-cycle motor had been worked at an uneconomically low point. However, an increase of 30% to 40% in the induction would appear to be obtainable, but a large increase in excitation is required. With but 30%

to 40% higher induction, and with the frequency halved, the short-circuit voltage would be but 65% to 70% of that with 25 cycles or, in other words, the voltage per turn in the field coil is but 65% to 70%. As the higher induction raises the armature counter electromotive force the field electromotive force can be increased in proportion for the same power-factor, or can be 30% to 40% higher than with 25 cycles. As the total field voltage, therefore, can be 30% to 40% higher, and the voltage per field turn is but 65% to 70%, it is evident that the number of field turns can be doubled without changing the

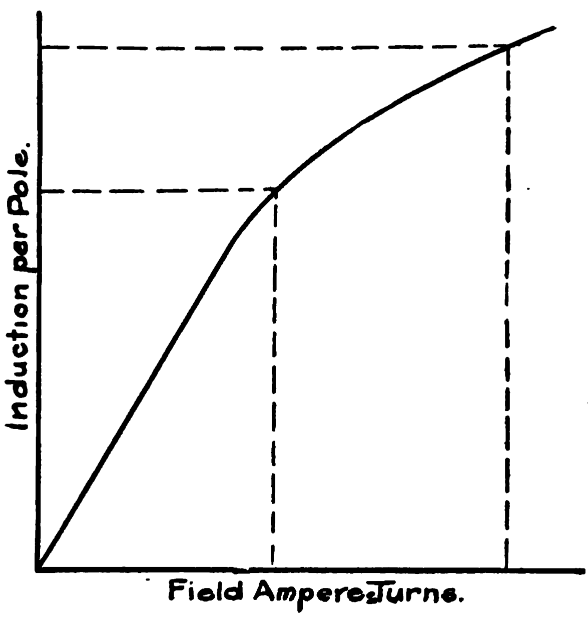


FIG. 3

ratio of the field inductive volts to the armature electromotive force. In other words, the field turns can be doubled if the frequency is halved. With the double field turns the field excitation can therefore be doubled, which is the requirement for the increased induction shown in Fig. 3. It is thus evident that halving the frequency will permit higher pole inductions, and therefore higher torque and output, with lower short-circuit voltage and better commutating conditions throughout. Also, this higher field induction is not necessarily accompanied by an increased iron loss, for the lower frequency of the alternating flux compensates for this. On the above basis it may be asked why a reduction to 15 cycles is proposed instead of to 12.5, or even to 10 cycles. There are several reasons for the choice of 15 cycles.

1. The motor can be worked up to so high a saturation at 15 cycles that there is relatively small gain with a reduction to 12.5 cycles, which would be about the lowest frequency to consider when the transformers and other apparatus is taken into account.

2. As the torque of the single-phase motor is pulsating instead of being constant, as in a direct-current machine, there is liability of vibration as the frequency of the pulsation is decreased. This effect becomes more pronounced the larger the torque of the motor, and is, therefore, of most importance in the case of a large locomotive. Experience shows that this tendency to vibrate can be damped out effectively in very large motors with a frequency of 15 cycles, but becomes more difficult to suppress as the frequency is further reduced. This is, in reality, one of the fundamental reasons for keeping up to 15 cycles instead of reducing to 12.5 or lower.

3. The lower the frequency the heavier the transforming apparatus on the car or locomotive. It is probable that with 12½ cycles instead of 15 cycles, the increase in weight and cost of the transforming apparatus would about counter-balance the decrease in the same items in the motors themselves, although the efficiency and power factor of the equipment would be slightly better with the lower frequency.

4. As synchronous converters will be used to some extent in connection with the generating plants for single-phase systems in order to feed existing direct current railways, the frequency of 15 cycles will be slightly more favorable than 12.5 as regards cost of the converters and the step-down transformers. The same will be true if motor-generators are used for transforming to direct current, also for induction motors.

Against the choice of 15 cycles may be cited the fact that there are other frequencies which represent a better ratio to 25 cycles when frequency-changers are to be taken into account. A low-frequency railway generating plant may require to tie up with some existing 25-cycle or 60-cycle plant; this can be done by interposing frequency-changers. Or it may be desired to obtain a lower frequency with a single-phase current from some existing higher frequency polyphase plant. By interposing the frequency-changer the single-phase railway load will not exert any unbalancing effect on the polyphase supply circuit, and at the same time the railway circuit can be regulated up or down independently of the three-phase generator circuit. In case the three-phase plant is operated at 25 cycles, then a two-to-one ratio of frequencies; that is, 12.5 cycles on the railway circuit, would give the best conditions as regards choice of poles and speeds in the frequency-changer sets. A five-to-three relation is given by 15 cycles, which is not nearly as good as the two-to-one ratio. A frequency of 16⅔ cycles would give a three-to-two ratio, which represents considerable improvement over the five-to-three ratio. Therefore, this slightly higher frequency may prove of advantage in some cases. The choice of this frequency, however, does not mean a new line of apparatus; for a well designed line of 15-cycle motor transformers, etc., should operate very well on a 16⅔-cycle circuit without any change whatever.

When transforming from 60 cycles, however, the 15 cycle gives a four-to-one ratio which is very good, and neither 12.5 nor 16⅔ cycles is very satisfactory. Therefore this 15-cycle frequency represents the best condition in transforming from 60 cycles, and fairly good conditions for transforming from 25 cycles; and by operation of 15-cycle apparatus at 16⅔ cycles a very good transformation ratio is obtained from 25 cycles. It may be of interest to recall that the old Washington, Baltimore and Annapolis Railway, which was the first road contracting for single-phase commutator motors, was laid out for 16⅔ cycles. There was considerable criticism at that time of the use of this frequency, but the statement which I have just made shows one very good reason for this frequency. A second reason is that 16⅔ cycles per second is 2000 alternations per minute, which permits a steam turbine driving a two-pole generator to use a speed of 1000 rev. per min., which is a very good one for large-turbo generators.

I have gone into the question of induction and frequency as affecting the commutation and torque. I will now take up the question of power-factor in the single-phase commutator motor. In a direct-current motor we have two electromotive forces which add up equal to the applied electromotive force; namely, the counter electromotive force due to rotation of the armature winding in the magnetic field, and the electromotive force absorbed in the resistance of the windings and rheostat

In the alternating-current motor there are these two electromotive forces, and there is also another one not found in the direct-current machine; namely, the electromotive force of self-induction of the armature and field windings due to the alternating magnetic flux in the motor. This inductive electromotive force exerts a far greater influence than the ohmic electromotive force for it has much higher values.

The inductive electromotive force lies principally in the main field or exciting winding of the alternating-current motor. There is a certain voltage per turn generated in the field coils, depending upon the amount of the field flux and its frequency, as stated before. This electromotive force per field turn is practically of the same value as the short-circuit electromotive force generated in the armature coil, as already referred to. I have stated that a short-circuit voltage of three or four volts per armature turn gave prohibitive designs and that it was necessary practically to double this. This means that the field coils also have six to eight volts per turn generated in them. The total number of field turns must, therefore, be very small in order to keep down the field electromotive force, for this represents simply a choke-coil in series with the armature. If the armature counter electromotive force should be 200 volts, for instance, which is rather high in practice with 25-cycle motors, then a field self-induction of half this value would allow about 14 turns total in the field winding. Compare this with direct-current motors with 150 to 200 field turns for 550 volts, or 60 to 80 turns for 220 volts. The alternating-current 25-cycle motor, therefore, can have only about 20% to 25% as many field turns as the ordinary direct-current motor. This fact makes it particularly hard to design large motors where there must be many poles. In the single-phase motor the induction per pole being limited by the permissible short-circuit voltage, it is necessary to use a large number of poles for heavy torques; but the total number of field turns must remain practically constant on account of the self induction, while in reality the number of turns should be increased as the number of poles is increased. With a given number of poles we may have just sufficient field turns to magnetize the motor up to the required point; but if a large number of poles should be required, then we at once lack field turns and must either reduce the field induction, and thus reduce the output, or must add more field turns and thus get a higher self-induction or choking action in the field, with a consequent reduction in power-factor. Here is where a lower frequency comes in to advantage, for, as I showed before, with the same relative inductive effect, the field turns can be increased directly as the frequency is decreased. The use of 15 cycles thus permits 67% more field turns than 25 cycles and raises our permissible magnetizing limits enormously. This problem is encountered particularly in gearless locomotive motors of large capacity. For increased capacity the driving wheels are made larger, thus permitting a larger diameter of motor, the length, axlewise, being fixed. But with increased diameter of drivers, the number of revolutions is decreased for a given number of miles per hour. With 25-cycle motors we soon encounter the above mentioned limiting condition in field turns; beyond this point the characteristics of the motor must be sacrificed, and even doing this we soon reach prohibitive limits. By dropping the frequency to 15 cycles, for instance, we change the whole situation. The induction per pole can be increased and the number of poles, if desired, can also be increased. The practical result is that, in the case of a high-speed passenger locomotive with gearless motors, a 700-h.p. 15-cycle motor can be got in on the same diameter of drivers as required for a 500-h.p. 25-cycle motor. Also a 500-h.p. 15-cycle motor goes in on the same drivers as a 360-h.p., 25-cycle motor. At the same time these 15-cycle motors have better all round characteristics than the 25-cycle machines as regards efficiency, power-factor, starting, over-load commutation, etc.

Returning to the design of the motor, there is one other electromotive force of self induction which may be considered; namely, that generated in the armature winding and in the opposing winding in the pole face, usually called the neutralizing or compensating winding.

Fig. 4 shows a section of the field and armature corresponding to the usual direct-current motor, or an alternating-current motor without compensating winding. In the direct-current motor the armature ampere-turns lying under the pole face tend to set up a local field around themselves, producing what is known as cross-induction. This produces no harmful effect except in crowding the field induction to one edge of the pole, thus shifting the magnetic field slightly and possibly affecting the commutation in a small degree. But if the armature is carrying alternating current this cross flux will generate an electromotive force in the armature winding, and this will be added to the field self-induction, thus increasing the self-induction or choking action of the machine. As the armature turns on such motors are much greater, in proportion, than the field turns, it is evident that the ampere-turns under the pole face can exert a relatively great cross-magnetizing effect. This high cross-magnetization generates a high armature self-induction which may be almost as much as the field self-induction. Further, this great cross-induction would tend to shift the magnetic field quite appreciably, thus affecting the commutation to some extent.

To overcome this serious objection, the neutralizing winding is added. This is a winding embedded in the pole face and so

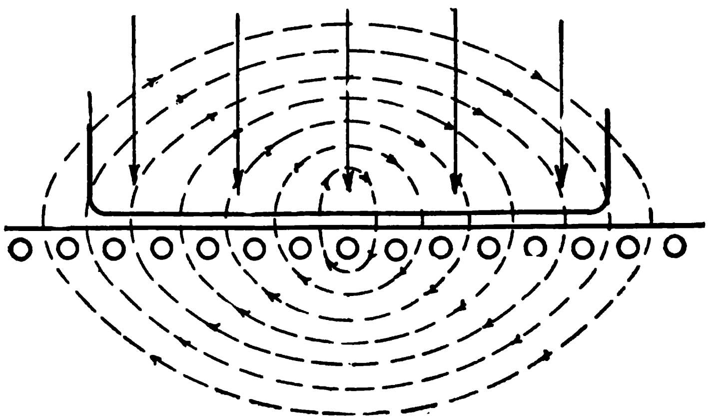


FIG. 4

arranged that it opposes the armature cross-magnetizing action. The arrangement is shown in Fig. 5. As it opposes and thus neutralizes the cross-induction set up by the armature winding, it eliminates the self-induction due to the cross-magnetization. It also prevents shifting of the magnetic field and thus eliminates its injurious effect on commutation. As the cross-flux is practically cut out the armature winding becomes relatively non-inductive. There is, however, a small self-induction in the armature and neutralizing windings, due to the small flux which can be set up in the space between the two windings, they being on separate cores with an air-gap between.

I have stated that the field turns of the alternating-current motor can be only 20% to 25% as many as in ordinary direct-current practice. It may be questioned how the field can be magnetized with so few field turns. This has been one of the most difficult problems in the motor. Obviously, one solution would be the use of a very small air-gap, but in railway practice there are objections to making the air-gap unduly small. Furthermore, if the armature has large open slots, as shown in Fig. 6, experience shows that a reduction in the clearance between the armature and field iron does not represent a corresponding decrease in the effective length of the air-gap, due to the fact that the fringing of the magnetic flux from the tooth tip of the pole face changes as the air-gap is varied. The most effective construction yet used consists in making the armature slots of the partially closed type as in the secondary of an induction motor. This is shown in Fig. 7.

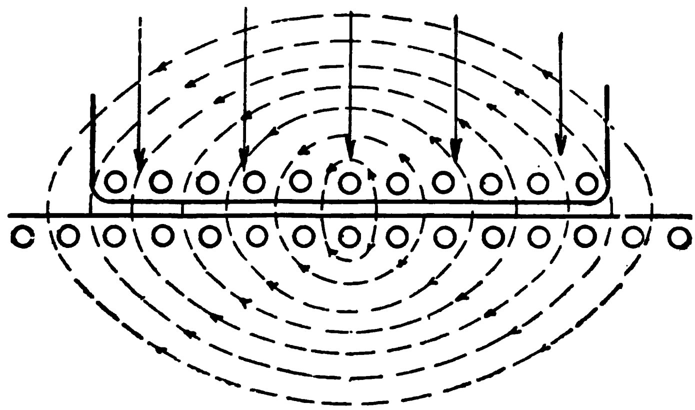


FIG. 5

With this construction practically the whole armature surface under the pole becomes effective, and the true length of air-gap is practically the same as the distance from iron to iron. With the increased effective surface, due to this construction, the length of air-gap need not be unduly decreased, which is of considerable importance in railway work.

A further assistance in reducing the required field turns is the field construction used in the single-phase motor. The magnetic circuit consists of laminations of high permeability and usually without joints across the magnetic path. The iron is also worked either below the bend in the saturation curve or, at most, only slightly up on the bend, except in the case of very low frequency motors where more field turns are permissible.

Taking the whole magnetic circuit into account, on 25-cycle motors about 80% of the whole field excitation is expended in the air-gap, while in direct-current motors, even with a much larger air-gap, as much as 40% to 50% of the magnetization may be expended in the iron and in the joints.

This armature construction with the partly closed slots has been found very effective in large, slow-speed, single-phase motors in which a relatively large number of poles is required. This construction is used on the New Haven 250-h.p., 25-cycle

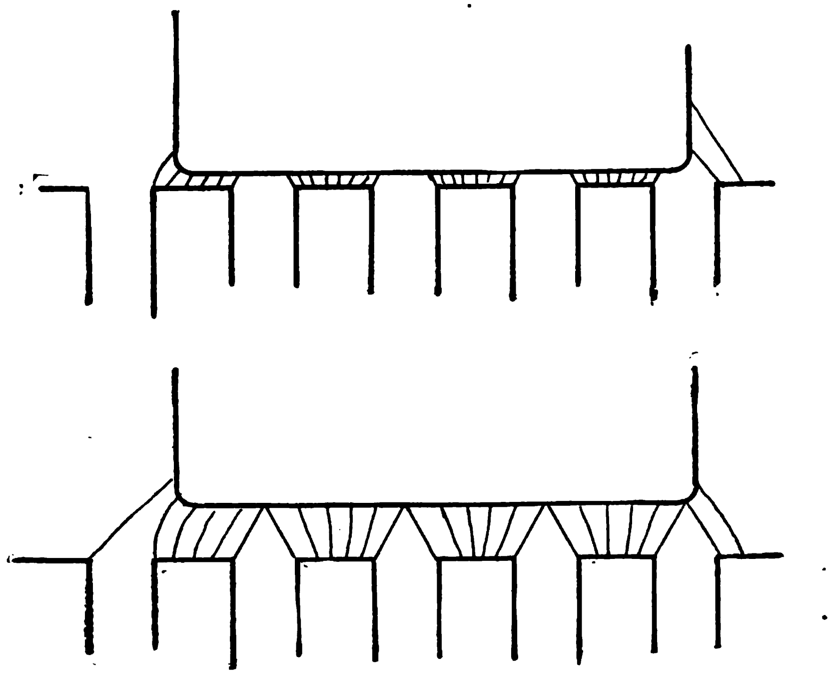


FIG. 6

motors; also on the 500 h.p., 15-cycle motor on the Pennsylvania locomotive exhibited at Altantic City at the Street Railway convention, last October. Geared motors for interurban service can be constructed with ordinary open slots with bands, and many have been built that way. The semi-closed slot, however, allows more economical field excitation.

It may be asked what the objection is to low power-factors on single-phase railway motors, aside from the increased wattless load on the generating station and transmission circuits. There is an objection to the low power-factor in such motors, a very serious one. This lies in the greatly reduced margin for overload torque in case the supply voltage is lowered. In railway work it is generally the requirement of abnormal loads or torques which causes a reduction in the line voltage; that is, the overload pulls down the trolley voltage just when a good voltage condition is most necessary. This is true of direct current as well as alternating current. In the direct current motor, however, such reduction in voltage simply means reduced speed but in the alternating current motor the effect may be more serious.

To illustrate, assume a motor with a power-factor of 90% at full load. The energy component of the input being 90%,

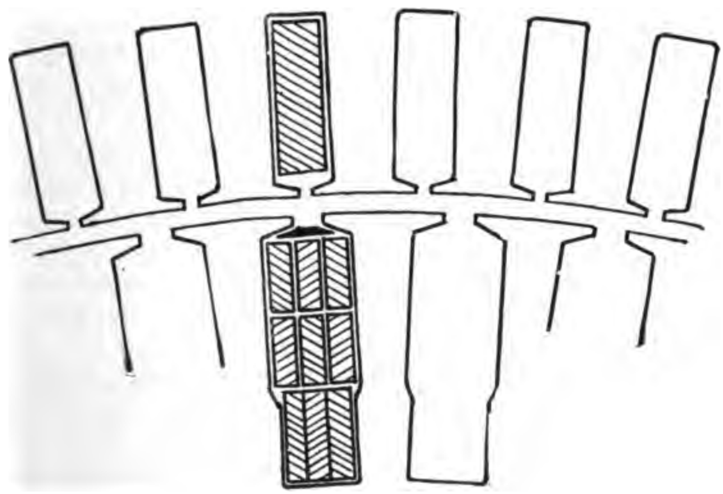


FIG. 7

the inductive component is about 44% or, putting it in terms of electromotive force the inductive volts of the motor are 44% of the terminal voltage. Neglecting the resistance of the motor, a supplied electromotive force of 44% of the rated voltage would just drive full-load current through it and develop full-load torque. With full voltage applied the motor could develop from five to six times full-load torque. Under abnormal conditions a drop of 30% in the line voltage would still give sufficient voltage at the motor terminals to develop two and one half to three times full-load torque. Let us next take a motor of 80% power-factor at full load. The inductive voltage would then become 60% of the terminal voltage, and therefore 60% of the rated voltage must be applied to send full-load current through the motor. This neglects the resistance of the motor, which, if included, means that slightly more than 60% of the voltage is required. With full voltage applied, this motor would develop about three or four times the rated torque. With 30% drop in the line voltage the motor could develop from one and one half to two times rated torque, which is hardly enough for an emergency condition.

Taking, next, a motor with 70% power-factor at full load it would require 70% of the rated voltage to send full-load current through the motor; with 30% drop in line voltage the motor could just develop full-load torque, and even with 15% drop it would develop only about one and one half times torque. As 15% drop is liable to occur on any ordinary system, this latter motor would be a very unsafe one.

It is evident from the above that it would be bad practice in railway work to install motors with very low full-load power-factors. In general, the higher the power-factor the more satisfactory will be the service, other things being equal.

I have endeavored to explain some of the problems which have been encountered in the design of single-phase commutator railway motors of sizes suitable for all classes of railway service. Here is a type of machine which has been known for a great many years, but which, until the last few years, has been considered utterly bad. In a comparatively short time it has been changed from what was considered an unworkable machine to a highly satisfactory one and this has been accomplished, not by any radically new discoveries, but by the common-sense application of well known principles to overcome the apparently inherent defects of the type. As an indication that the motor is making progress in the railway field, I will mention that the first commercial single-phase railway motors have not been in use more than four or five years, and yet at the present time there have been sold by the various manufacturers in this country and Europe, a total capacity of approximately 200,000 to 250,000 h.p., a very considerable part of which has been put in operation. Considering that the motor was a newcomer in a well established field, the above record is astonishing. However, it may be safely predicted that what has been done in the last five years will hardly make a showing compared with what will be done during the next five years, for the real field for such motors, namely, heavy railway work, has hardly been touched.

A paper presented at the 225th Meeting of the American Institute of Electrical Engineers, New York, February 14, 1908.

THE NON-SYNCHRONOUS GENERATOR IN CENTRAL STATION AND OTHER WORK

BY W. L. WATERS

That an induction motor could act as a generator and return power to the line when driven at a speed above that of synchronism, has been known for many years. It has, however, always been regarded as more or less of a scientific curiosity, and except in the case of the Swiss three-phase mountain roads, where the motors are sometimes allowed to run as generators to brake the train on descending heavy grades, the non-synchronous generator has had but few commercial applications. The fact that the characteristics of this generator are such that it must receive a lagging current from the system, the magnitude of which is for a given machine definitely decided by the slip of the generator above synchronism, combined with the fact that when connected to a circuit is has no definite voltage and frequency of its own, make it lack the flexibility of the synchronous generator. In 1895, Mr. B. G. Lamme proposed running a non-synchronous generator with an unloaded synchronous motor, the generator to supply the watt component and the motor the wattless component of the current in the system. But though this suggestion rendered the non-synchronous generator a practical machine, it is easily understood that on account of the lesser flexibility when compared with the synchronous generator, it has not appealed to the central station engineer as a desirable addition to his equipment.

The question as to the advisability of adopting the non-synchronous generator for power station work, was decided adversely by engineers at the time when steam engines and water turbines were the only practical prime-movers. But to-day we have to deal with steam turbines and gas engines, and the coming of these two new types of prime-movers has altogether changed the situation in regard to the use of this generator for power station work. It often happens in such cases that the real meaning and possibilities of the introduction of types of machinery with such fundamentally new characteristics as the steam turbine and gas engine, are not recognized until they are accidentally forced upon us. This has been the case in the present instance; the question of the use of non-synchronous generator with steam turbines was not seriously considered until it was brought up indirectly. In 1904 a copper smelting and rolling company was installing a 1200-kw., 200-volt, direct-current generator for

Fig. 1—Non-Synchronous generator installed at a copper-smelting and rolling mill.

electrolytic work. It was desirable to continue the good steam economy on variable loads, the small floor space and reduced maintenance of the steam turbine, and at the same time to generate 200-volt direct current. A 1200-kw., 6000-ampere, 200-volt, 1800-rev. per. min., direct-current turbine generator was not considered practical, and a non-synchronous generator together with a synchronous converter was suggested as an alternative. It was finally decided to adopt this type of equipment, and a 1200-kw., six-phase, 140-volt, 30-cycle, 1800-rev. per min. generator together with a 1200-kw., six-phase, 150-rev. per min. converter was installed to supply the required 6000 amperes direct current at 200 volts. A direct-current exciter for the converter was provided, so that the direct voltage could be varied from 100 to 230 volts without any danger of instability. The exciter is compound-wound to give constant voltage on the direct-current side of the converter, and the power-factor gradually rises from about 25% at no load to about 96% at full load. When starting up the set, the converter is run up to speed from an auxiliary source of direct current, and the generator by its turbine. They are then thrown together, the generator driving the converter as a synchronous motor, and the converter supplying the magnetizing current of the generator. The governor of the turbine decides the frequency of the set, and the slip of the converter behind the generator is proportional to the load, being about 1% at full load. This equipment has been running now for about three years and operates perfectly. The generator is similar in arrangement to the old open-type turbo-generator, and in consequence is rather noisy, but with the modern enclosed type of generator it is possible to arrange the air circulation better, and to obtain as a result a much quieter running machine.

This installation is given in detail, as it is one instance where the adoption of this apparently inflexible type of generator resulted in an installation, which combines the flexibility of the standard direct- or alternating-current generator with the capacity for heavy overloads of the synchronous converter, and the reliability and robustness of construction of the non-synchronous generator. No other electrical equipment which could have been installed would have given the good results that were obtained. And though the existing conditions rather forced the choice of the equipment in this case, the results so thoroughly met expectations, that engineers began to consider whether the development of the last few years in regard to prime-movers had not changed the non-synchronous generator from a scientific curiosity, to a generator possessing great advantages for certain conditions of power station work.

General characteristics of the non-synchronous generator. As most engineers are more familiar with the characteristics and performance of the induction motor than they are with those of the commercial non-synchronous generator, it will be well to show how the characteristics of the two machines are allied. An induction motor of given characteristics carrying a certain definite load, runs at a fixed speed relatively to that of synchronism, and it takes a current the magnitude and phase of which are definite. The torque exerted by the motor is proportional to the product of the current induced in the short-circuited secondary, and the magnetic flux. The electromotive force and the current induced in the secondary, and hence the torque, are proportional to the rate at which the secondary conductors cut the primary magnetic field, that is, to the slip of the rotor above or below the speed of synchronism. As the speed of the motor gradually rises to that of synchronism, the current in the secondary, and the torque gradually fall, till at the speed of synchronism they both become zero. If the speed of the machine still continues to increase, the secondary conductors cut the primary flux in the reverse direction, and the induced electromotive force, the secondary current, and the torque become negative; that is, the machine requires mechanical power to drive it above the speed of synchronism. The machine now returns electrical power to the circuit, and has become a generator. When running as a motor, the current is never in phase with the impressed voltage, for two reasons: (1), the motor requires a certain wattless magnetizing current; and (2), the motor windings, both primary and secondary have a certain amount of self-induction. This makes the current lag behind the impressed voltage by an angle ϕ, depending on the characteristics of the machine, and on the load it is carrying. When the machine runs above synchronism as a generator, it still takes from the circuit the wattless magnetizing current, and the circuits still possess their self-induction. And as the watt component has reversed in direction, this will mean that the primary current lags less than 180° behind the voltage impressed by the circuit on the generator, hence the current leads the electromotive force supplied by the generator to the circuit. Thus we have as a fundamental characteristic of the non-synchronous generator, that for a given load it runs at a certain definite speed above that of synchronism, and that, (*a*) it supplies a watt current which represents the power delivered by the generator to the circuit, and (*b*) it takes a wattless magnetizing current from the system, the magnitude of which depends on the voltage and on the watt component of the current. Hence this type of generator cannot supply a lagging current to the outside circuit, and can only deliver power to a circuit which can provide the lagging magnetizing current required by a non-synchronous generator: for any given speed, the magnitude and phase of the current which the generator will supply is definitely fixed. Also as the wattless component of the current varies in magnitude when the load of the machine changes, we must have in circuit some apparatus which can supply a variable amount of lagging current, and which will keep the voltage of the circuit constant. It is these apparently rigid and inflexible conditions which have prevented any extensive use of the non-synchronous generator, and it is only because under certain modern conditions these limitations do not mean serious disadvantages, that this generator is now put forward as an important part of a power station equipment.

Usually the load on a power station is either non-inductive or has a lagging power-factor, so that if this type of generator is used, the lagging current required by the generator, and perhaps also by the outside circuit, must be artificially supplied. There are two ways of obtaining the lagging current required by the non-synchronous generator: (1), from a condenser; (2), from a synchronous generator or an over-excited synchronous motor. It would not be desirable commercially, to install a condenser specially to supply the required lagging current, as the cost would be prohibitive; but a large cable system has quite a considerable electrostatic capacity, and the lagging current supplied by this system will usually help greatly in reducing the size of the necessary synchronous machine. In any case, however, it is necessary to have a synchronous machine, either a motor or a generator, in the circuit, in order to set the frequency and the voltage. If we have the non-synchronous generator running together with a synchronous generator, the latter machine supplies all the lagging wattless current required by the non-synchronous generator and the outside circuit, while the voltage of the circuit is decided by the excitation of the synchronous generator. The distribution of the watt component of the current between the two machines, is decided by the governors of the prime-movers. The load which the non-synchronous generator takes, depends on the percentage slip by which it leads the synchronous generator, and the remainder of the load is taken by the synchronous generator. When additional load comes on the station, it first comes on the synchronous generator, and then, as this machine slows down and allows the slip of the non-synchronous generator to increase, part of the load is transferred to this latter machine. In any case, the voltage regulation of the system is that of the synchronous generator, and the voltage of the circuit under any condition of load is decided by the excitation of this machine. If we have the non-synchronous generator running together with a synchronous motor or synchronous converter, then the same remarks apply. The voltage regulation is that of the synchronous machine, and the voltage of the circuit is decided by the magnitude of its excitation. When the load increases, the additional load comes first on the synchronous machine, energy being supplied to the system from the momentum of its rotating part, and then as the machine slows down a little, the load is transferred to the non-synchronous generator, the synchronous machine supplying simply the additional lagging current required by the generator when carrying the additional load. The synchronous machine supplies at all times all the lagging wattless current in the circuit, and the governor of the prime-mover driving the non-synchronous generator, decides the frequency of the circuit, the synchronous machine slipping behind the generator an amount just sufficient to allow this latter machine to supply all the power required by the circuit.

Non-synchronous generators in power station work. Obviously the disadvantage of the non-synchronous generator for power station work is, that it cannot carry a lagging wattless current, that it requires an additional lagging wattless current to excite it. The power-factor of the current supplied by such a generator is a direct measure of the amount of wattless current required to excite it under that particular load. The power-factor which can be obtained in designing any non-synchronous generator, depends on the size, speed, voltage, and frequency of the machine. Low speed, high voltage, and high frequency, all tend to lower the power-factor which can be obtained.

Table 1 gives the characteristics of steam-turbine and gas-engine-driven non-synchronous generators of from 1000 kw. to 10,000 kw. for 2200 and 13,200 volts, and for 25 and 60 cycles. The table shows that on high-speed 2200-volt generators, the power-factor rises as high as 98.25 per cent. and that we can obtain on such machines a power-factor which averages 97% to 98% from one-half to one and one-quarter load, while the no-load magnetizing current is less than 10% of the full-load current of the machine. This being the case, the fact that these generators require a wattless current to excite them, ceases to be a serious objection, and it is seen that the one important limitation of this type of machine is, that it cannot supply lagging wattless current to the outside circuit. Of course the low-speed, 60-cycle machines, are relatively poor as regards power-factor and exciting current, so that the use of non-synchronous generators would not be advocated under these conditions, unless their other characteristics made them particularly advantageous for the conditions under which they were to be used. It will also be seen from Table 1 that another advantage of this type of

TABLE I

Kilo-watts	Rev. per min.	Volts	Efficiency, Load 1	Efficiency, Load 0.75	Efficiency, Load 0.50	Power-factor, Load 1	Power-factor, Load 0.75	Power-factor, Load 0.50	No-load current	Slip
25 Cycle—Turbo-Alternators										
1000	1500	2200	97.6	97.7	97.5	97.0	97.5	97.0	8.3%	0.75%
		13000				95.0	95.9	96.5		
2500	1500	2200	98.2	98.2	97.9	97.9	97.3	96.4	8.3	0.48
		13000				96.5	96.9	96.0		
5000	1500	2200	98.3	98.2	98.0	98.0	97.7	97.4	8.5	0.46
		13000				96.5	97.0	96.5		
10000	750	2200	98.5	98.4	98.2	98.2	98.0	97.5	8.1	0.40
		13000				96.8	97.3	97.1		
60 Cycle—Turbo-Alternators										
1000	1800	2200	97.6	97.7	97.5	96.4	96.9	96.4	9.5	0.75
		13000				94.0	95.0	94.5	11.5	
2500	1800	2200	98.2	98.2	97.9	97.2	96.8	96.2	9.5	0.48
		13000				94.5	95.3	94.8		
5000	1200	2200	98.3	98.2	98.0	96.0	97.2	97.0	9.5	0.45
		13000				94.5	95.6	95.5		
10000	720	2200	98.5	98.4	98.2	97.6	97.6	97.1	9.5	0.40
		13000				95.3	95.6	95.5		
25 Cycle—Gas-Engine-Driven Alternators										
1000	94	2200	96.7	97.1	97.2	94.0	94.2	92.0	16.5	1.5
		13000				89.3	90.9	88.7	18.0	
2000	83	2200	97.0	97.4	97.6	95.5	95.1	94.0	16.5	1.4
		13000				92.4	93.2	90.7		
3500	75	2200	97.1	97.5	97.7	95.7	95.2	94.2	16.5	1.4
		13000				92.6	93.4	91.0		
60 Cycle—Gas-Engine-Driven Alternators										
1000	3	2200	95.5	95.7	96.0	88.8	88.5	84.6	25.0	1.8
		13000				83.0	81.	73.3	40.0	
2000	82	2200	96.0	96.3	96.5	89.5	89.2	85.6	24.0	1.7
		13000				83.5	81.8	75.0	38.0	
3500	75	2200	96.3	96.5	96.7	90.8	89.5	87.0	22.5	1.6
		13000				85.0	83.3	77.0	35.0	

generator, is the extremely high efficiency at all loads that is obtained in high-speed machines. This means that these generators have a very low temperature rise at normal rated load, and that they have a very large overload capacity. The normal ratings of the individual machines given in the table were chosen so that their characteristics would be best at from one-half to one and one-quarter rated load. All the machines given, can generate from two and one-half to five times their rated output, and as far as general characteristics are concerned could be rated up 50%. It was stated above, that the slip of the non-synchronous generator relatively to the synchronous generator, must increase from no load to full load, in order that the former may carry its due share of the load. So if we wish the load always to be automatically divided between the two machines, we must adjust the governor of the synchronous prime-mover so that its drop in speed from no load to full load, equals the drop in speed of the non-synchronous prime-mover plus the full-load slip of the non-synchronous generator. This means that the speed and frequency of the synchronous generator must change with the load, but we see from the slip given in the table that this change is unimportant. The slip varies from 0.4 per cent. to 0.75 per cent. in high-speed machines and from 1.4 per cent. to 1.8 per cent. in low-speed machines, and this is about as close as the governors will regulate in any prime-mover.

The greatest commercial field for the non-synchronous generator, is undoubtedly in connection with turbine-driven generators. This type of generator is more suitable both mechanically and electrically for high-speed work than any other type of electrical machine. The squirrel-cage secondary with heavy copper bars, each bar held in a separate closed slot, and practically requiring no insulation, is an ideal construction mechanically, and is one which can be operated at very high temperature without damage. Comparing this with the rotating magnets of the standard synchronous turbo-alternator, the difference is very great. The magnet winding of a synchronous turbo-alternator consists of a number of turns of thin strap separated by insulation. The windings often reach high temperatures due to overload at low-power-factors, and are subject to heavy centrifugal stresses and a potential difference of 125 volts to ground. We can see that such a construction does not compare with that of the squirrel-cage rotating secondary of a non-synchronous generator. And as a breakdown on the field of a synchronous turbo-generator usually puts the machine out of commission for a couple of weeks, we can see the mechanical advantages possessed by the non-synchronous generator. The simplicity in construction and insulation of the rotating parts, the ease with which the centrifugal stresses necessarily present can be taken care of, and the absence of a complicated winding and brush gear, necessarily tend to reduce the cost of the non-synchronous generator compared with that of the standard synchronous generator. Of course the actual cost of any machine depends on the performance specification to which it is designed, and on how closely the machine is rated, but it can readily be seen that the non-synchronous generator offers facilities for cheaper design and manufacture which are not presented by the synchronous generator.

The excitation of the non-synchronous generator. A synchronous generator requires direct-current excitation, while a non-synchronous generator requires alternating excitation. The non-synchronous generator is excited by a lagging current taken usually from a synchronous machine, and as this synchronous machine requires direct-current excitation to produce this lagging current, it can be said that indirectly the non-synchronous generator does require a direct-current exciter. But on account of the small air-gap of this type of generator, it requires much less excitation than a synchronous generator. The actual capacity of the exciters which are required by a power station consisting of non-synchronous generators, depends on the power-factor of the load on the system. The capacity required will usually vary from one-quarter to one-half of that which would be required for the corresponding synchronous generators. Of course if we have a cable system with high electrostatic capacity, this will supply part of the required lagging excited current and will reduce the size of the required exciter. The charging current of the New York Interborough system is given as about 105 amperes at 11,000 volts; that is, about 2000 kilovolt-amperes, and that of the New York Edison system is about 40 amperes at 6600 volts; that is, about 450 kilovolt-amperes. We see from Table I that the capacity-charging current of the New York Edison system is sufficient to supply full-load magnetizing and wattless current required by a 2000-kw. 6600-volt, 25-cycle turbo-driven non-synchronous generator when running on a non-inductive external load. In the same way the capacity-charging current of the Interborough system would be sufficient to supply the wattless current of a 10,000-kw. 11,000-volt, 25-cycle turbo-driven generator. If we had a cable system such as the Interborough distributing at 20,000 volts, we would have a charging current of 190 amperes at 20,000 volts, which would be sufficient to supply the wattless component for 40,000 kw. in 22,000-volt, 25-cycle turbo-driven non-synchronous generators.

So we can see that the electrostatic capacity of a large cable system will play an important part when we come to consider the introduction of such generators into some of the large New York power stations.

In a system consisting of non-synchronous generators supplying power to synchronous converters, it is unnecessary to have any exciters or synchronous machines in the power station. The first converter put in circuit, must be run up to speed from the direct-current side, and then thrown on the generator circuit, when it will excite the latter, and the voltage will be decided by the excitation of the converter. We can see from Table I that the power-factor of a non-synchronous generator can be made to remain practically constant from one-half to one and one quarter load. This means that the amount of wattless lagging current taken by the generator throughout its normal working range, will be practically proportional to the watt current. Hence assuming that we can neglect the capacity-charging current of the cable system, if we have a number of converters running on the circuit, we can adjust the shunt excitation of each converter so as to give the correct voltage at no load, and the series excitation can be adjusted to obtain any desired voltage-characteristic as the load comes on the system, the converters compounding the generators by their series winding. This compounding of the generators as the load comes on any sub-station, affects of course all the other sub-stations fed from those generators; so if we are not regulating for constant voltage, it may be advisable in some cases to introduce artificial self-induction into the converter feeder circuits so as to over-compound these circuits rather than the generators, and avoid disturbing the voltage on other unloaded sub-stations. In a large system, the capacity current of the cables can not be neglected, so the wattless current to be supplied by the converters will not be directly proportional to the load. Such a system usually requires constant voltage at the direct-current terminals, and in such cases it may be found advantageous to install compound-wound converters with automatic voltage regulators to control the shunt excitation. The voltage regulators would then serve to control the voltage of the generators, and to keep that constant, while the series winding would serve to compound each individual feeder in order to compensate for the voltage-drop in that feeder. In such a system, all the regulators controlling the voltage on a given group of generators would be tied together, so that any one regulator could not act before, or act against the others, and make the shunt excitation of the individual converters different.

If there is no electrostatic capacity in the system, the power-factor of the converters is practically the same as the power-factor of the generators; but if there is capacity in circuit which helps to supply the lagging current, then the power-factor of the converters will be higher than that of the generators. Taking once more the Interborough system, and assuming there are 75,000 kw. of 11,000-volts turbo-driven non-synchronous generators in the power station, and 75,000 kw. in synchronous converters in the sub-station, then the capacity current supplies 13 per cent. of the wattless current taken by the generator on full load, and we have a full-load power-factor for the converters of 98 per cent. Such a power station of non-synchronous generators, having no direct-current exciters and exciting circuits, is much simpler as regards cables and switchboard connections than a similar station with synchronous generators, and is much simpler to operate. There is no necessity for synchronizing the generators; they are simply run up to speed and are then thrown on the line in series with a reactive-coil, (to limit the rush of current). The reactive coil is then short-circuited, and the generators are automatically excited from the converters and take care of themselves. The governors of the prime-movers are controlled by pilot motors from the switchboard, and the load can be distributed at will among the different generators without adjusting the excitation to keep the power-factor constant, as would be necessary with the synchronous generator. This gives an ideally simple station, as there are no auxiliary circuits, and the switchboard is practically limited to the main generator and feeder switches and instruments.

Short-circuits and resonance. During the last few years we have heard a great deal regarding resonance and high power surges in large installations with distributing cable systems of high electrostatic capacity. We can investigate these phenomena mathematically in detail, if we choose to make a number of more or less arbitrary assumptions, but it is the author's opinion that at present we are only justified in describing these phenomena in general terms. By a high-power surge is meant the oscillation sometimes set up in a system by a sudden rush of current, such as a short-circuit, and which has usually the fundamental frequency of the circuit. The power represented by the surge, is proportional to the square of the value reached by the current in the first sudden rush, and the rise in voltage is directly proportional to the surge of the current. Resonance effects, cover the extremely high rises of potential which take place in a circuit containing self-induction and capacity, when the frequency of the circuit has a certain value depending on the amount of induction and capacity in circuit. In ordinary power systems, resonance cannot generally take place at the normal frequency of the circuit, but there are usually higher harmonics of this normal frequency introduced by distortion of the fundamental

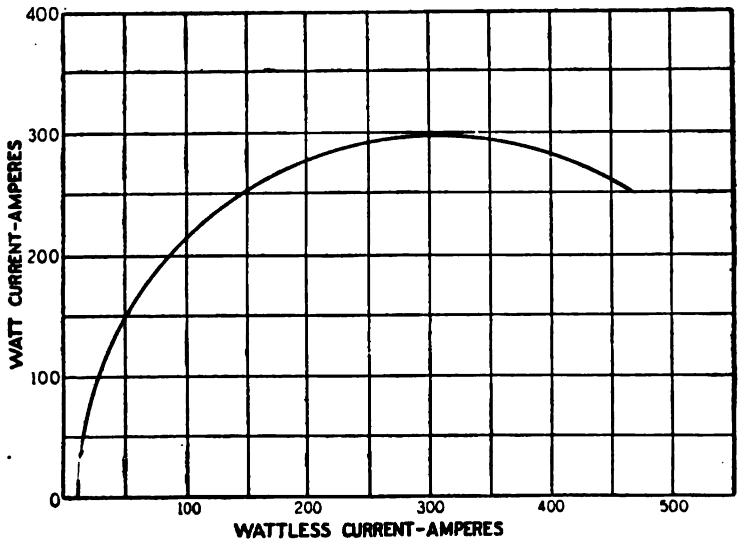


FIG. 2.

wave-form, and there may be resonance and high voltage due to one of these high harmonics.

This short analysis shows at once why a power station of synchronous generators, is so liable to suffer from surges and resonance. Synchronous generators and motors will give a greater sudden rush of current, or surge, in the case of short-circuit than almost any other class of machine. And though they have wave-forms which approximate closely to sine waves on no load, these wave-forms become so distorted by armature reaction on load, and change so with the magnitude and phase of the current, that there is an excellent chance of introducing such harmonics as will produce resonance. If we were deliberately to try to choose conditions which would be most liable to give trouble from high-power surges and resonance, we could not well choose anything that would be worse than synchronous generators feeding synchronous motors through a cable system of high capacity. The non-synchronous generator is a great contrast to the synchronous generator in this respect, as it tends rather to eliminate disturbances from the line than to originate them. A short-circuit on a system means that the voltage falls to zero, consequently any non-synchronous generator on the circuit becomes dead, and does not tend to supply either power, current, or voltage to the short-circuit. Further, the wave-form of the electromotive force of a non-synchronous generator is virtually a sine wave for all loads, and it has no tendency at all to introduce higher harmonics which might produce resonance. If the synchronous machines supplying the wattless current in the circuit have a badly distorted wave-form, the magnetizing current of the non-synchronous generator will alsc be distorted, but there will be a strong tendency to damp out all harmonics in the electromotive force wave-form of the system. And we can say that, generally speaking, the non-synchronous generator acts as a strong damper to remove all harmonics in the electromotive force wave-form of the system, introduced by distortion of the wave-form of the synchronous machines. This distortion in a synchronous machine, is due to the armature reaction of the watt component of the current, rather than the wattless, so we see that the best conditions as regards freedom from distortion and harmonics are obtained by the use of a synchronous converter or unloaded synchronous machine, rather than a loaded synchronous generator or motor to supply the wattless current required to excite a non-synchronous generator.

Fig. 2 shows approximately the relation of the watt component to the wattless component of the current supplied by a 2000-kw. non-synchronous generator, the curve being for its normal rated voltage of 11,000 volts; for a different voltage the values of current, both watt and wattless, should be multiplied by the direct ratio of the new voltage to 11,000 volts. We can see from this, that the magnitude of the watt current bears a definite relation to that of the wattless, and that the watt current, and consequently the load on the machine, cannot change without the wattless current also changing. Further, for each point on the curve, the slip of the non-synchronous generator ahead of the synchronous machine has a *certain definite* value. This shows that when a short-circuit comes on a system consisting of a non-synchronous generator and synchronous generator or motor, the short-circuit will come on the synchronous machine. If the voltage drops to zero, the non-synchronous generator will be dead; but if the short-circuit is not severe enough to reduce the voltage of the system to zero, then it may still supply current to the circuit. The amount which it supplies will depend on the way in which the excitation of the synchronous machines is changed by the automatic voltage regulators. But a change in load which can be taken care of by the voltage regulators, hardly comes under the class of short-circuits, and as these latter effects are the only serious ones, we will consider them alone. We see from the above that the non-synchronous generator takes no part in the sudden surge of current which occurs on a short-circuit, so that this surge cannot be greater than that which is supplied by the synchronous machines in circuit.

The sudden surge which takes place when any synchronous machine, whether generator, motor, or converter, is short-circuited is equal to:

$$\frac{\text{Electromotive force of synchronous machine}}{\text{self-induction in circuit}}$$

After the current has flowed for an appreciable time, so that the magnetism of the synchronous machine has had time to change, the armature reaction cuts down the electromotive force generated, and the current falls to the value commonly known as the short-circuited value, this being the value of the current on a continuous short-circuit. The 5000-kw. 11,000-volt Manhattan generators will give a continuous short-circuit current about three times full-load current, but the instantaneous value of the current on a sudden short-circuit is about five times this; that is about fifteen times normal full-load current. If these generators are supplying synchronous converters, these converters will also supply power to the short-circuit. The 1500-kw. Manhattan converters give about full-load current on a continuous short-circuit on the alternating-current side, with the self-induction of the transformers and reactive-coils in circuit, and the instantaneous value on sudden short-circuit is about three times this value. So a short-circuit on a system consisting of the Manhattan generators supplying power to synchronous converters will give, on sudden short-circuit, a rush of current equal to eighteen times the total full-load current of the genera tors in circuit, while after a short period the value of the short-circuit current will fall to about one-fifth of this value. Assuming now that we had non-synchronous instead of synchronous generators in the power station, the short-circuit current would be limited to that from the converters, and the sudden surge would be equal to three times full-load current. The voltage of the system would fall to zero, and the converters would supply a gradually decreasing current to the short-circuit until their rotational energy was all expended, and they had come to rest. We see then that with non-synchronous generators in the power station, the magnitude of the sudden surge on a short-circuit would be reduced to one-fifth of that which would take place with the present synchronous generators. This means that the voltage-rise would be only one-fifth, and the power of the surge would be only one twenty-fifth. These figures do not need any comment.

There is one point, however, that must be considered when operating non-synchronous generators on the system containing considerable electrostatic capacity, and that is that the individual generator units are not too small. A non-synchronous generator can be excited by the lagging current from a condenser, and the voltage to which it will be excited depends on the size of the condenser. In a system consisting of non-synchronous generators and synchronous machines we might, as the result of opening circuit-breakers by line disturbances, have just one generator and one small synchronous unit left running on the line. The capacity current of the cable system would then tend to build up the voltage of the machines until the saturation of the magnetic circuit prevented any further rise. Taking the 2000-kw. 11,000-volt non-synchronous generator, the current curves of which are shown in Fig. 2, the magnetizing current at 11,000 volts is 9 amperes. If the capacity-charging current of the cables is 100 amperes at 11,000 volts, and the synchronous machine is so small as to take a negligible lagging magnetizing current, it would probably mean that the voltage of the machines would build up to double the normal. If, however, the smallest machine on the circuit were a 10,000-kw. generator, a 1500-kw. synchronous motor or synchronous converter, the rise in voltage would not be more than 10 per cent.; if the minimum size generator unit had been 20,000 kw. there would be no rise in voltage; so that this is a condition which can be taken care of when laying out the station.

Distortion of the wave-form introduces higher harmonics, and may cause resonance or cross-currents. In a synchronous generator or motor, the wave-form of the magnetism is usually badly distorted as the load comes on the machine, this distortion being greater the higher the power-factor, and the greater the load. This distortion of the magnetic wave, introduces higher harmonics into the wave-form of the electromotive force generated in the armature conductors. The most important harmonic introduced is the third; but the fifth, seventh, ninth, and higher harmonics are also usually presented. In a three-phase winding, the third harmonic, and also harmonics of this third harmonic, appear in the electromotive force between the neutral and outer terminals, but not in the electromotive force between the outer terminals. They therefore appear in a three-phase, four-wire system, or in a three-phase system with grounded neutral. The other harmonics appear, no matter what the connections are. Though the presence of these harmonics may not cause harm in any individual case, it is always possible that there may, under certain conditions of circuit and load, be harmonics of a frequency sufficiently close to that of resonance to cause serious rise of potential. And if generators of different characteristics run together, or if there are loads of different magnitude and phase, or different excitation on the synchronous generators or motors, cross-currents are liable to be produced between the machines; this is especially the case in running with a grounded neutral. Synchronous converters are very much better than any other class of synchronous machines as regards distortion of wave-form when operating with unity power-factor; they have practically no armature reaction, and the electromotive force wave generated under such conditions is approximately a sine. So the above remarks on synchronous generators and motors, only apply to synchronous converters to a limited extent.

Non-synchronous generators have no distortion of field due to armature reaction, and so long as the iron in the magnetic circuit is not saturated, the electromotive force wave-form of these generators is virtually a sine wave for all conditions of load. This means that there can be no cross-current between non-synchronous generators, due to difference in wave-form, and that they have no tendency to produce resonance in the circuit. Furthermore a non-synchronous generator acts as the strongest possible damper in a circuit; and if there is any surge, unbalancing of phases, distortion of wave-form or hunting present, the non-synchronous generator will tend to damp it out, and to restore the original condition of steady sine-wave operation. If we then have a system consisting of non-synchronous generators supplying power to synchronous converters, it would be as nearly perfect as possible in its freedom from surges and resonance. The synchronous converter would give the minimum distortion of any synchronous machine, and the non-synchronous generator would tend to damp out any disturbance that occurred on the line. Such a system would certainly be very much superior to the synchronous generators and synchronous motors in regard to liability to disturbances from resonance and surges, and in all probability the engineers of such a system operating with grounded neutral would hardly know that such phenomena existed.

I have endeavored to show that the non-synchronous generator is very much superior to the synchronous generator from almost every point of view, for the purpose of supplying power to motor-generators and synchronous converters through an underground cable system; and that synchronous converters are less liable to introduce line disturbances than synchronous motors. In some cases it might be considered advisable to install both synchronous and non-synchronous generators, or the station might be one in which the units first installed were synchronous generators, and the later extensions were non-synchronous generators In such cases it is readily seen that the advantages as outlined above, are obtained to a degree which depends on the ratio of the number of non-synchronous to the synchronous generators. It should be remembered that the non-synchronous generator and synchronous converter, give the best combination to ensure freedom from line disturbances, and that the synchronous generator and synchronous motor give the worst; combinations of the two systems lie between these two.

Small power stations. There have now been considered in detail, large systems which can easily provide the necessary lagging exciting current for the non-synchronous generator, either from the charging current of the cable system or from the synchronous motors or synchronous converters in the system.

With smaller power stations which supply power direct to motor and lighting circuits, the conditions are not so favorable to the non-synchronous generator, as this generator is primarily one for high power-factor loads, and it is at a distinct disadvantage in a station in which the load is of low power-factor. The advantages of the non-synchronous generator as outlined above are, however, so great that each particular case should be considered to see whether it will allow of its use. Usually the load on such a station having low power-factor, consists mainly of motors during the day time, whereas the heavy peak load is the lighting load at night. We can therefore install synchronous generators sufficient to carry the day motor load, and non-synchronous generators to assist in carrying the lighting load at night. Let us take a 60-cycle station with a day load of 2500 kilovolt-amperes which will probably have a power-factor of 70 per cent. and a night load of 4000 kilovolt-amperes with a power-factor of 98 per cent. And assume further that we have two 1250-kilovolt-amperes synchronous turbo-generators to carry the day load, and two 1000-kilovolt-ampere non-synchronous generators to assist in carrying the night load. This night load consists of 3850 watt kilovolt-amperes and 800 wattless kilovolt-amperes, and the two non-synchronous generators require in addition 980 wattless kilovolt-amperes to excite them. We shall then have the two synchronous generators carrying a load of 2500 kilovolt-amperes at 70 per cent. power-factor and the non-synchronous generator carrying a load of 2250 kilovolt-amperes at power-factor 0.98.

It is nearly always more economical to supply wattless current in a power station from unloaded high-speed synchronous motors, than from the main synchronous generators. This is more especially the case with steam-turbine or very slow-speed units, as such machines cannot be economically designed with the good regulation and the margin on the fields necessary to handle properly a low power-factor load. Such a machine to carry satisfactorily a certain kilowatt load at power-factor 70 per cent. will be about double the size of a unit to carry the same kilowatt rating at unity power-factor. In the station considered, we have assumed that the synchronous generators supply all the wattless current required for the non-synchronous generators and outside circuit. It would be better, however, to make the synchronous generators 1000 kilovolt-ampere units with poor regulation, and install also a 1500-kilovolt-ampere high-speed synchronous motor to supply all the wattless current. This should give a cheaper and more flexible installation, as we would be able to run the non-synchronous generators without the synchronous generators at any time, using the synchronous motor to excite them. The non-synchronous generators would require no direct-current exciters, exciting circuits, or switch panels: they would probably be cheaper than the synchronous generators, and would be simpler to handle, and less liable to break down. So we can see they have such important advantages that they should be carefully considered in each individual case before deciding to adopt synchronous generators alone.

Other applications of non-synchronous generators. In the above remarks, the non-synchronous generator has been dealt with more especially as a steam-turbine-driven unit for generating alternating current. This type of generator, however, often presents important advantages for other and more especial conditions. Two of the most important of such cases are gas-engine-driven alternators, and steam-turbine-driven direct-current units. The advantage of the non-synchronous generator for gas-engine-driven units, is of course that it does not require the extreme uniformity of speed required by a synchronous generator, and the advantage of its application for direct-current generation by turbine units is, that by the use of a non-synchronous generator and synchronous converter we can avoid the use of a direct-current turbo-generator.

Gas-engine-driven units. With modern tandem and twin-tandem gas engines designed along certain well-established lines, giving respectively two and four impulses per revolution, gas-engine-driven alternators can be and undoubtedly are run in parallel. But to obtain satisfactory operation, heavy fly-wheels and heavy dampers on the pole-faces of the alternators are necessary. Considered apart from the engine itself, however, such fly-wheels mean a considerable increase in cost, and sometimes in the floor space taken up by the engine, and also a loss in efficiency due to the increased bearing friction and windage. And there is necessarily a loss in the dampers on the pole-faces of such gas-engine-driven alternators, on account of the irregularity in speed of the gas engine, though this loss would not be detected except in a gas-consumption test, when running in parallel with other units. Instead of synchronous units, we can install non-synchronous generators and have high-speed synchronous motors running light, to provide the necessary lagging current for the outside circuit and for exciting the generators. In this case any change in load comes first on the synchronous motors, causing a change in their speed, and in consequence a transferring of the change in load to the generator. And as the voltage of the generator would be decided by the excitation of the synchronous motors, the voltage regulation of the station is that of the synchronous motors. Hence for constant potential it may be advisable in some cases to control the excitation of all the synchronous motors by one automatic voltage regulator. The size of the direct-current exciter necessary for the synchronous motors would depend on the power factor of the load on the station, and would be greater, the greater the lagging current required by the external circuit. Generally speaking, the size of the exciter required, would be from one-quarter to one-half of that necessary for the corresponding synchronous generators. The probable arrangements would be, a direct-connected exciter on each synchronous motor, which could also be used as a starting motor; and one gas-engine-driven exciter would also have to be installed for starting up the first synchronous motor.

Taking as the load on such a 2200-volt, 25-cycle power station, 20,000 kilovolt-amperes at 70 per cent. power-factor, we would have four 5000 kilovolt-ampere, 75 rev. per min. synchronous generators, each requiring a 125-kw. exciter; or four 3500-kw. 75 rev. per min. non-synchronous generators, together with four 4500 kilovolt-ampere 500-rev. per min. synchronous motors with 60-kw. direct-coupled starting motor-exciters. Each synchronous motor would supply the 1000-kilovolt-amperes exciting current required by one non-synchronous generator, together with 3500-kilovolt-amperes wattless current for the external circuit. The relative efficiencies on the load of 70 per cent. power-factor are as follows:

	Synchronous generator	Non-synchronous generator and synchronous motor
Full load	95.7—(a)	94.0
0.75 "	95.1—(a)	93.6
0.50 "	94.0—(a)	92.5

These efficiencies do not take into account the allowance (a) to be made for additional losses due to the increased friction of the larger fly-wheels, and the losses in the dampers or solid pole-faces which occur with the gas-engine-driven synchronous generator. These additional losses will reduce the efficiency of the synchronous generator below that of the non-synchronous generators set. The cost of the electrical equipment would not be very different in the two cases, and as the larger fly-wheel, shaft, and bearings, required for the synchronous generator would increase the cost considerably, it is probable that the non-synchronous generator equipment would be found a good deal the cheaper. It must be remembered that this is an extreme case, because the low power-factor of 70 per-cent. taken for the outside load is very much against the non-synchronous generator. If the power-factor were higher, the result would be much better.

It might be supposed that unless we had very heavy fly-wheels on the gas engine we would have the same trouble with hunting of the non-synchronous generator and synchronous motor that we would have with the synchronous generator. But such is not the case. There will undoubtedly be cross-currents between the machines, the magnitude of which will depend on the variation in the speed of the gas engine, but it will be practically impossible to break them out of step. The worst effects of this interchange of current between the machines, will be the heating and losses in the armature conductors, and the pulsation in voltage due to the interchange of wattless current. This pulsation of voltage will be diminished by dampers on the pole-faces of the synchronous motor, but it will usually be perceptible when only one generator is running. As these gas-engine-driven units will be used mainly for power work in mills, the slight pulsation of voltage will be unimportant.

Non-synchronous generators are not put forward as the only possible solution of the gas-engine-driven alternator question; but as the most practical, and that which will recommend itself most highly to the conservative power station engineer and manufacturer. It is by no means settled that heavy fly-wheels and powerful dampers are a practical, and advisable solution of the parallel running difficulties.

Steam-turbine-driven direct-current units. The other special case for the use of the non-synchronous generator above referred to—the use of such a generator, together with a synchronous converter for the production of direct current—is to meet the special case in which a steam turbine is desired as a prime-mover. Reasons which might compel the choice of the steam turbine are numerous: small overhead space, small floor space, poor foundations, objection to the vibration of reciprocating engines, high steam economy required over a wide range of loads, reduced maintenance and supervision—all these might influence the choice of prime-mover. And as the direct-current turbo-generator, particularly for 250 and 125 volts, has as yet hardly established its position as a conservative and reliable machine, some kind of alternating-current generator would be used in combination with a motor-generator or synchronous converter. Two years ago an electric railway and light company, wished to install an auxiliary 3000-kw. 300-volt direct-current steam-driven generating equipment in the basement of their new public service building. As the head-room was limited to about 12 feet, and as the vibration would be objectionable, reciprocating engines were out of the question. They installed two 1500-kw. horizontal steam-turbine-driven synchronous alternators, and two synchronous motor-generator sets. This would have been an ideal case for a non-synchronous generator and synchronous converter. The converters could be started from the direct-current system, and when up to speed would have excited the non-synchronous generators; no exciters nor exciting circuits would be necessary, the voltage being controlled by the excitation of the converters. The equipment which was installed has a combined full-load efficiency of about 86 per cent. while the combined efficiency of a non-synchronous generator and synchronous converter to do the same work, would have a full-load efficiency of about 95 per cent. In addition it would probably have cost about one-third less.

	1000 kw.	2000 kw.	3000 kw.
1. Non-synchronous generator	97.5	98.0	98.25
2. Synchronous converter	97.0	97.5	97.75
3. Combined efficiency of non-synchronous generator and synchronous converter	94.5	95.5	96.0
4. Engine-type generator	93.5	94.25	94.5

In comparing a turbine-driven non-synchronous generator and synchronous converter, with a steam-engine-driven direct-current generator, the former is found to be a more flexible equipment, one which will carry heavier overloads, and is usually cheaper. We can obtain any compounding desired by means of a compound winding on the converter, and by use of transformers we can have converters of different voltages to supply different direct-current systems. We can place the converter at a distance and transmit the power to it at a high voltage, or we can split up or arrange the equipment as we please. The efficiency is slightly higher on the non-synchronous generator equipment than on the engine-type, as can be seen from the following table of full-load efficiencies for 270-volt generators.

There are many indications that the day of the large engine-type direct-current generators is past. The inaccessibility of the brushes, the difficulty of building and maintaining a commutator of large diameter, and the numerous other drawbacks of

Fig. 2

this type of machine, have caused it to be regarded as an undesirable addition to a power station. It is a question whether the non-synchronous generator and the synchronous converter are not superior to the engine-type direct-current generator in almost every case, and it should always be carefully considered when a new direct-current station is laid out, or when any extensions are added to existing plants.

I have endeavored to show that the one great disadvantage of the non-synchronous generator—its inability to carry a lagging wattless current load—should not always prevent its successful adoption, and that the important advantages it possesses in its excellent mechanical construction, high efficiency, good characteristics in regard to short-circuits and resonance, strong balancing and damping action, absence of rotating windings or collector rings, absence of direct-current excitation and exciting circuits, ease of parallel running facility for control of load by governor, and general simplicity and flexibility of operation—all these make it in many cases by far the most advisable machine to adopt. The non-synchronous generator suffers from the fact that it was judged and condemned in the early days of electric power generating stations. At that time there was no real field for this generator, but the introduction of steam turbines and gas engines, and the modern development of large power stations have so fundamentally altered conditions, that the non-synchronous generator is no longer an interesting curiosity, but one of the most promising types of generator for power station equipment. The record of three years in service, places this machine on a demonstrated commercial basis, and while it may have limitations, it possesses so many advantages and its sphere of usefulness is so large, that in the opinion of the author it must be acknowledged to offer greater future possibilities than almost any other type of power station equipment.

APPENDIX.

The following data on the steam consumption obtained from tests in the copper smelting and rolling plant referred to earlier in the paper, are of interest in comparing the efficiencies of the two types of direct-current generating equipment. The first column gives the actual steam consumption of the 1200-kw. steam-turbine-driven non-synchronous generator and synchronous converter, the turbine being run with 140 lb. steam pressure, 28 in. vacuum and 135 degrees superheat. The second column gives the corresponding figures on a Corliss engine and direct-connected generator, the steam consumption being based on a minimum consumption of 12.5 lb. per indicated horse power at 80 per cent. of full load.

Pounds of steam per kilowatt-hour at direct-current terminals

Load	Steam turbine equipment	Corliss engine equipment
0.5 load	21.2 lb.	23.5 lb.
0.75 "	18.2	19.8
1. "	17.5	20.3
1.25 "	17.5	23.2

A paper presented at the 225th Meeting of the American Institute of Electrical Engineers, New York. February 14, 1908.

SOME DEVELOPMENTS IN SYNCHRONOUS CONVERTERS

BY CHARLES W. STONE

It is not the intention to make this paper a history of the development of the synchronous converter, but rather to point out some of the more important improvements which have been made in the last few years.

In this country the synchronous converter has become practically an indispensable piece of apparatus, some of the largest lighting and railroad companies being entirely dependent upon it. Abroad the conditions are different, as the motor-generator has been used almost exclusively until within the last few years, when the motor-converter was introduced. The motor-converter is a compromise between the synchronous converter and the motor-generator.

It may be of interest to give at this time some idea of the increase in capacity of these machines in the last ten years on one of the large lighting systems, as this will give some idea of the tremendous development in machines of this type. In 1897, on the particular system in question, there was installed less than 1000 kw. total capacity, and the largest machine was 500 kw.; on the same system in 1907, considerably over 100,000 kw. were in operation, the largest units being 2000 kw.

Most of the larger systems using synchronous converters operate at 25 cycles, but during the last four or five years many systems using 60 cycles have adopted synchronous converters and have found them very reliable.

I think it can be safely said that 60-cycle synchronous converters, even when used for 600-volt railway work where the demands of the service are most severe, can be considered thoroughly reliable and successful, machines as large as 1000 kw. being in successful operation.

The general tendency in the design of synchronous converters has been toward higher speeds, which naturally means reduction in the space occupied by them, lower first cost, less weight etc. All these changes result in smaller buildings, cheaper foundations, and consequently lower fixed charges.

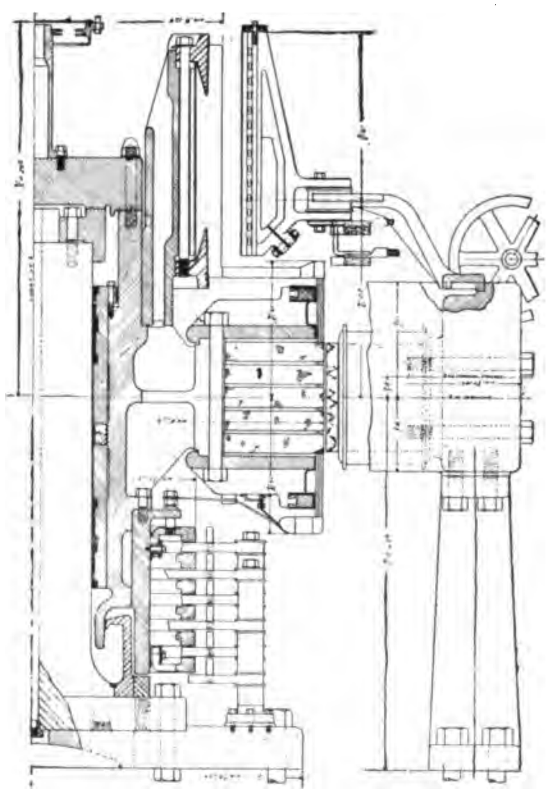


FIG. 1.

As an illustration of the changes that have been made, I shall cite one example. The 2000-kw., 25-cycle, 250-volt synchronous converter as originally designed operated at 115 revolutions and had 26 poles. It occupied a floor space 190 in. by 204 in. and the total weight was approximately 186,000 lb. The newer vertical machine is circular in form, has 18 poles, and operates at 167 revolutions. The diameter is 182 in. and the total weight about 130,000 lb.

Vertical synchronous converters. The vertical synchronous converter is so new that it seems advisable to point out some of its essential characteristics. The most novel features are in the shaft and bearings. The shaft, unlike that of the horizontal machine, is stationary; in fact it is nothing but a pedestal supported by and fastened solidly to the foundations. There is only one bearing, which carries the entire weight of the revolving structure. In the first machine built this bearing consisted simply of two cast-iron plates, one of which was fastened to the top of the pedestal and the other being bolted to the spider of the armature. Fig. 1, a cross-sectional view of the machine, shows more clearly this construction. Oil is pumped up through

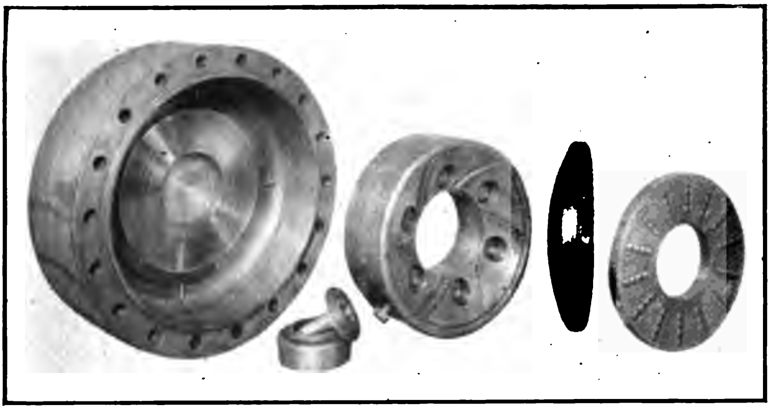


FIG. 2.

a central hole in the pedestal and forced out between the cast-iron plates, forming an oil-film on which the machine revolves, making virtually a frictionless bearing.

In addition to the main bearing, use is made of the entire length of the interior of the spider for a guide bearing. A cast-iron sleeve lined with babbitt is fitted into the spider to form the bearing surface. As the only weight on this bearing is that due to the unbalancing of the rotating structure, the bearing should last indefinitely. The oil, after leaving the top or supporting bearing, passes along the pedestal, (thus oiling the guide bearing) down to the pocket at the base of the machine were it is drained off and used over again. Since the first machine was built, a new type of bearing has been tried which gives promise of success, although only a few months' experience has been obtained as yet.

Fig. 2 shows in general the parts which are used to make up this bearing. The cup-shaped cast-iron piece shown is fastened to the top of the pedestal and forms a seat for the hardened steel bearing plate and carrier, the steel plate being simply doweled in place. Both sides of this plate are accurately ground so that it can be reversed in case of any damage to one surface. It can readily be seen that this construction of the two lower members of the bearing makes it self-aligning.

The top part of the bearing is bolted to the armature spider and is similar to the top of the oil-pressure bearing, except that another hardened steel plate is doweled in place on the under part of this casting to form the wearing surface. Between these steel plates is a bronze carrier with a number of hardened steel rollers placed radially, thus forming the roller bearing. Oil is pumped by a small low-pressure pump to this roller bearing and is drained off after passing through the guide bearing in exactly the same manner as with the oil step.

The stationary part carries the field spools and is split vertically so that the two halves can be drawn apart, making the armature accessible for inspection or repairs. This frame is supported on a number of cast-iron pedestals.

By the above construction it will be noted that the field frame is entirely independent of the rotating structure, making it easier to assemble the machine.

The armature being revolved around the pedestal, it is not possible to obtain any end-play, as in a horizontal machine. Some means must be provided to make the wear on the collector rings equal; this is accomplished by designing the brush rigging in such a manner as to make it possible to stagger the brushes and thus cover the entire width of the collector rings. In addition there are placed on each ring some graphite brushes which act as lubricators.

Fig. 3 is an elevation of the first 2000-kw. machine of the vertical type which has been constructed in this country. By reference to this Fig. it is readily seen how accessible the machine is. It is possible to walk around the machine and see and adjust all the brushes on both the commutator and the collector rings without climbing up on a bearing pedestal or going down into a pit, as would be necessary in a large horizontal-shaft machine. The bearings in the 2000-kw. vertical machine can be taken out, inspected, and replaced in a little over two hours, which would hardly be possible in a horizontal machine of the same size.

The construction above outlined makes it possible to build machines occupying minimum floor space; in fact it has been found possible in stations which have been laid out for 1000 kw., machines, horizontal shaft of the old type, to place a similar number of vertical machines of double the capacity.

Voltage regulation. The next matter is that of voltage regulation. With a synchronous converter, as is well known, it is not

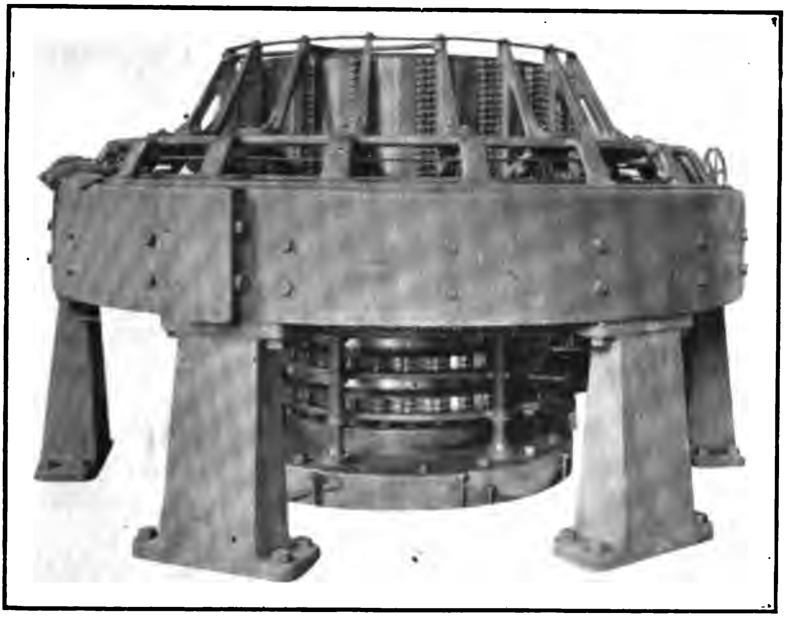


FIG. 3.

possible to regulate the voltage on the direct-current side of the machine by means of the field rheostat, as is done with a direct-current generator, without changing the power-factor; for the ratio between the impressed alternating voltage and the direct voltage is fixed by the design of the machine. Hence where voltage regulation is necessary, as for lighting work, charging storage-batteries etc., some means of changing the impressed alternating voltage is necessary.

A number of different methods have been used to accomplish this result, which I shall describe briefly:

1. On the step-down transformers used with the converter, taps can be placed either on the primary or the secondary side and switches used to transfer from one tap to another. This scheme has many objections and is seldom used now. If the taps are on the primary, oil-switches would have to be used if the voltage were at all high. Such switches would be practically out of the question. If the taps are on the secondary, a dial-switch can be used, but only with the smaller size machines, as it is difficult to build a dial-switch to handle large currents satisfactorily, except at prohibitive expense. This method is also objectionable as it means fluctuation in the lights whenever the switch is moved to a different tap.

2. The common way of obtaining control of the voltage in railway work is to insert in the leads from the secondary of the transformer a reactance, thus furnishing a means of changing the impressed alternating voltage. This method, while simple and effective with the limited ranges in voltage required for such work, would not be applicable for large ranges in voltage. Too much reactance may cause pulsation troubles and it also has a bad effect on the entire system.

3. The arrangement in most general use to-day is to connect an induction regulator between the secondary leads of the transformer and the synchronous converter, by which it is possible to obtain almost any range of voltage within the capacity of the machine. This scheme of operation is in such general use that it is not necessary to describe it in detail. The principal objection to this arrangement is that another piece of operating machinery is used with each synchronous converter outfit, increasing the cost, requiring valuable floor space, and making it necessary to open the secondary leads from the transformer, a serious complication with large low-voltage machines.

4. The next development in this line took place abroad, where an entirely different scheme was used. A few machines of this type have also been built by one of the large manufacturing companies in this country. This method makes use of an alternating-current booster or bucker, mounted on the same base with the synchronous converter. The field has the same number of poles as the converter, and the armature is mounted on the same shaft as the synchronous converter armature. Alternating current is generated in this armature, and can be made to add its voltage to or be subtracted from the impressed voltage, according to the direction

of the excitation. This booster is usually placed between the collector rings and the main armature of the converter, and the taps from the collector rings are connected to equidistant points of the booster armature; similar points on the booster armature are connected to the synchronous converter armature, thus placing the two in series, separate and distinct windings for each phase being used.

The principal objections to such an arrangement are that here again we have an additional operating machine, as in the case of an induction regulator. Extra weight is added to the shaft between its points of support. The ventilation of the converter armature and its accessibility are impaired. Any serious trouble with this smaller machine results in the dismantling of the main synchronous converter in order to repair the small booster.

Another way to construct such a machine is to make it a revolving-field machine, mounting the field on an extension of the shaft beyond the bearing of the collector-ring end of the synchronous converter.

As the armature is stationary, the leads from the secondary of the transformer are led directly to this winding, and from this winding to the collector rings of the synchronous converter. This arrangement has the twofold advantage of being accessible, and not interfering with the ventilation or accessibility of the synchronous converter. This booster can be applied to any standard converter; and being overhung, it is possible to carry a spare machine which can be placed in position quickly and without interfering with the body of the main synchronous converter.

5. The next development is very radical and is unlike any of the other schemes used. It was first proposed by J. L. Woodbridge some time ago. It has been known for some time that the ratio of conversion between the alternating-current and direct-current sides of a synchronous converter could be changed by varying the width of the pole-face. The Woodbridge method makes use of this idea in a very simple and yet effective way.

Fig. 4 shows a two-pole synchronous converter equipped in accordance with this idea. Each field pole is divided into three sections, on each of which are two windings. One of the windings on each section is the main shunt winding, and the other is the regulating winding. All the main windings are connected in series and excited in the ordinary manner. The regulating windings, however, are connected differently. The windings on the two outer sections of all poles are connected in series with one another, and the windings of all the central sections are connected in series with one another, and these two groups are connected in series.

The voltage of the direct-current side of the converter is increased by exciting all the outer sections in a direction to assist the main shunt field, and the middle section an equal amount in opposition to the main field. This condition is shown in Fig. 5. If both these windings are excited in the opposite direction the direct voltage will be lowered. Fig. 6 shows this condition. All that is needed in this arrangement is a field rheostat in the regulating field circuit in addition to the main field rheostat ordinarily used.

The first question that comes up with this scheme is its

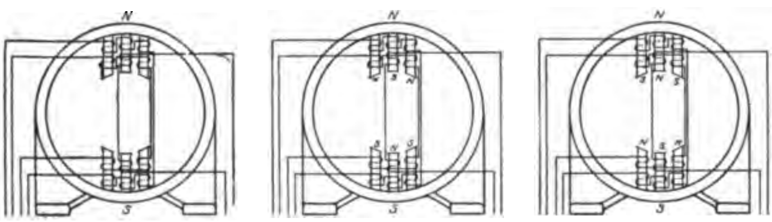


Fig. 4 Fig. 5 Fig. 6

FIGS. 4, 5, 6.

effect on the power-factor. A number of machines arranged this way have been designed and placed in operation. With these machines the power-factor can be held constant at all loads, yet all the range in voltage desired can be obtained.

6. Since this method was proposed, another and still simpler method has been brought out. This scheme was proposed by Mr. J. L. Burnham. Instead of making each pole with three sections and with two windings on each, only two sections are used. On each section only one winding is used. The large section corresponds to the main shunt winding on an ordinary synchronous converter, while the regulation is obtained entirely by changing the excitation of the smaller section, exciting it in one direction to boost the voltage, and in the other to lower the voltage.

Anti-hunting devices of many types have been designed and put in operation, most of which have been reasonably successful. The latest, and in many ways the most efficient form of bridge, is formed by placing some copper rods directly through the face of the pole tips, although completely surrounded by the magnetic material. These copper rods are all joined together by heavy copper rings, thus forming a complete squirrel-cage winding similar to that used on the rotor of an induction motor. These rods being placed directly through the pole face are naturally in the main flux, and consequently form very efficient dampers.

Nothing has been said as yet about transformer connections to be used with synchronous converters. There are many conditions existing in different parts of the country which have made it advisable to use some special form of connection for the transformers, but the general practice is to use the diametrical connection with all six-phase machines. This connection is particularly useful in lighting work, as it provides a ready means for obtaining a neutral. With three-phase converters the transformers are usually connected in delta. In many cases they are connected in Y to obtain a neutral, which can be done if special provision is made in distributing the windings in the transformers.

A paper presented at the 225th meeting of the American Institute of Electrical Engineers, New York, February 14, 1908.

SOME FEATURES OF RAILWAY CONVERTER DESIGN AND OPERATION

BY J. E. WOODBRIDGE

There are now in service in this country in railway work alone, synchronous converters with an aggregate capacity of nearly 1,000,000 kw. In spite of the wide use of this machine, some features of its design and operation are not generally clearly understood, or are quite generally misunderstood. It is the purpose of the following paper to take up three of these features as follows.

Six-phase versus three-phase converters. Of the above aggregate capacity, something like one-third consists of machines with six collector rings tapped into the armature winding at six points per pair of poles and termed six-phase converters, although the electromotive forces delivered to them are as truly three-phase as are those delivered to machines with three collector rings. Although it is generally known that the addition of three collector rings to a given three-phase converter reduces the armature $I^2 R$ losses considerably on unity power-factor, it has been heretofore assumed that wattless currents increase these losses of both types of converters by about the same quantity, but not in the same proportion, so that the gain of the six-phase machine is slight on low power-factors.

It has heretofore been shown mathematically, and noted in actual practice, that the armature conductors of a converter nearest the collector ring taps, run warmer than those midway between the collector ring taps. The distribution of the armature $I^2 R$ losses (assuming a winding of uniform cross-section, which is the invariable construction) is shown in the upper part of the accompanying diagram, Fig. 1, the two curves of which represent the theoretical $I^2 R$ loss of a six-ring machine run with the same load, in one case with six-phase, and in the other case with three-phase supply, both at unity power-factor. These curves assume theoretical voltage ratios which are closely approached in practice, but neglect the losses due to unconverted power such as unbalancing, core-loss, incipient hunting, harmonics set up by differences in wave-form, etc., These losses are small, and affect both curves by about the same amount. The vertical scale is given in terms of the heat developed in the same winding

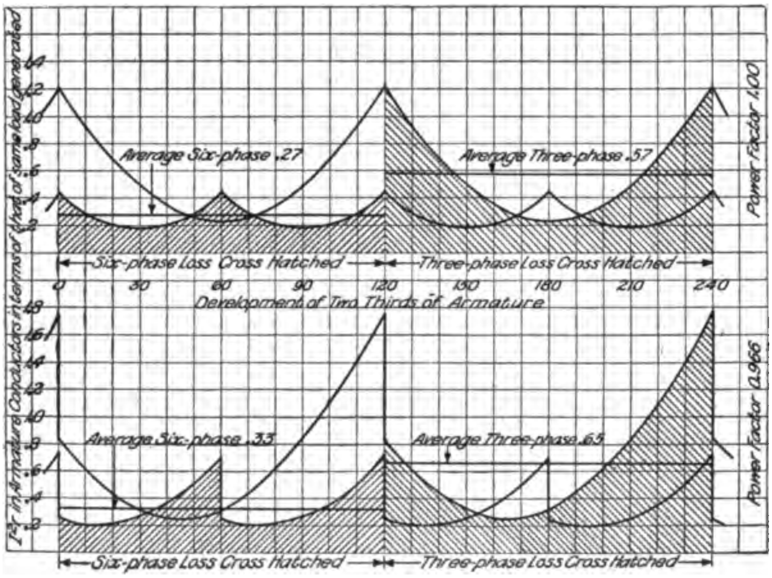


FIG. 1—Distribution of copper losses in armature conductors of converter

when generating the same power in direct current mechanically driven. It will be noted that in this case the operation of the machine as a three-phase converter as compared with its operation as a six-phase converter, increases the average $I^2 R$ loss slightly over 100 per cent. and increases the $I^2 R$ loss in the unfavorably situated bars adjacent to the collector rings almost 200 per cent.

It has been generally assumed that this considerable advantage of the six-phase over the three-phase machine is reduced in case of lower power-factors. It can be shown mathematically (see appendix 1) that the distribution in case of a phase displacement of 15 degrees giving a power-factor of 96.6 per cent.; that is, a wattless current equal to about 27 per cent. of the energy current, is as indicated in the lower half of Fig. 1. In this case it will be noted that the average heating of the whole winding for the same load is in the case of the six-phase operation increased from 0.27 to 0.33 of the reference figure, which is the heat developed by the same direct current load mechanically derived. In the case of the three-phase operation, the average $I^2 R$ loss rises by a lesser proportion from 0.57 to 0.65, but the addition of the wattless current has also the peculiar effect of shifting the heat distribution from one side to the other of the collector ring tap, considerably reducing the heating of the bars to one side of the tap and greatly increasing that of the bars on the other side. A lagging component shifts the heating to one side of the taps, and a leading current to the other side. It will be noted that the bar to one side of the collector ring tap is heated in the case of the six-phase operation to the extent of 0.71 of the reference figure, or about twice the average and three and a half times the minimum, whereas the corresponding bar of the three-phase machine is heated to the extent of 1.75 times the reference figure, or three times the average and seven times the minimum, and two and a half times the maximum with the same machine worked six-phase. While the distribution of the heating between slots is not as bad as that between conductors in the three-phase case, since conductors adjacent to the taps lie in the same slots with others midway between taps, a considerable difference of temperature will exist between the two conductors in one slot in case of a heavy overload at low power-factor. It will be shown later that practically all overloads on compound-wound machines are at a low power-factor. Lower power-factors increase this heating and further crowd it into a few bars.

Even if the maximum heating were the same for the two methods of operation, the addition of three collector rings might be warranted by the better distribution of six-phase operation, but with the maximum heat generation two and a half times as great (even with a good power-factor) with only three collector rings the argument is that much stronger.

Of course, a three-phase converter for a given output may by increasing its size be built with more armature copper than a six-phase converter of the same rating; but in any event the three-phase machine may be safely increased in rating some 40 or 50 per cent. with no increased losses, and with a correspondingly higher efficiency by the addition of three more collector rings and, if necessary, a corresponding extension of the commutator. This results in a corresponding reduction of core-loss per kilowatt capacity, which is a great aid to efficiency in railway work of low load-factor.

The arguments against the six-phase form of converter are three in number: first, the increased number of parts of the machine; secondly, the additional number of cables; thirdly, the alleged relative complication of the transformer circuits.

Unless extreme care is taken in the construction of a converter, to get the magnetic reluctance of all poles exactly the same, it is found that the commutation of any three-phase machine is improved by the addition of equalizing rings over and above those constituting the three collector rings. Six or more equalizing rings being advisable for this reason, the increased complication of the machine for six-phase operation is reduced to the addition of three collector rings, the necessary brush rigging and terminals. These additions are negligible in the case of large machines where each of three rings must be considerably broader than each of six in order to carry double the current, and where also the use of six rings allows the brush rigging to be divided into two equal parts, one each side of the shaft, where with three-phase converters two-thirds of the brush rigging must be on one side of the shaft. Further, the six narrow rings are better ventilated than three broad ones, and run cooler.

In the matter of cables, the objection to six-phase machines applies only to small units where the whole current of one of the three phases can be carried in one cable. In machines of 500 kw. or more, even at railway voltage, it is convenient to use six alternating current cables, two in parallel on each phase, for the supply of a three-phase converter, and in larger machines it is necessary to do so. The six-phase machine has an alternating current input per ring practically equal to one-half the direct current output, so that wherever two cables or a multiple of two are used for one pole of the direct-current output, cables of the same size may be used for the alternating-current leads, the machine being as convenient in this respect as the three-phase converter.

In the matter of transformer connections, the so-called diametrical connection is almost invariably used, each transformer having one secondary winding, the ends of which are connected respectively to two collector rings, the connection being even simpler than that of three-phase converters, in that no " Y " or delta need be made. If reactive-coils or other devices are serially connected in the low-tension alternating-current circuits, these need be, and commonly are, only three phase; one phase being connected in series with each diameter of the converter, and so to speak, boosting or lowering the voltage of both ends of the diameter. (Fig. 2). This is a positive advantage for the six-phase equipment, in that the winding of the serially connected devices need carry only one-half of the current of the winding of a similar device for a three-phase converter.

For the above reasons all converters of 500 kw. capacity and

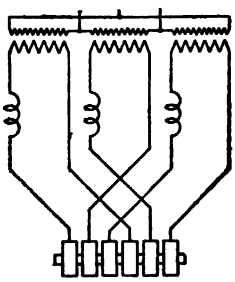


FIG. 2—Six-phase diametrical connection with three-phase reactance. Rings shown in order of connection to armature winding

over, made by one manufacturing company in this country are built for six-phase operation.

The alternating-current starting of synchronous converters. Some 50 per cent. of the above mentioned total of railway converters in service in this country, are equipped with switches and connections for starting the machines from rest by means of the direct application of alternating electromotive forces to their armature windings through the collector rings, these electromotive forces being a fraction of those subsequently switched on for operation. In spite of the extensive use and general success of this method of starting, advocates and users of other methods attribute great disadvantages to it. Following is a more complete statement of the case than has heretofore been set forth.

A line of 25-cycle converters with pole-arcs equal to 75 or 80 per cent. of the pole-pitch, with air-gaps of one-quarter to three-eighths of an inch, and with full load armature ampere-turns per pole approximately equal to the shunt field ampere-turns per pole (at rated voltage normal speed unity power-factor no load) and with short-circuiting squirrel-cage, anti-hunting winding embedded in the pole faces, will in general start from rest with some 20 to 25 per cent. of rated alternating voltage impressed across their collector-rings, and will take at this voltage at rest approximately twice full load current; that is, 40 to 50 per cent. of full-load volt-amperes, this current having a low power-factor, as the machine is acting under this condition as an induction motor with a variable and rather wide air-gap, the pole-face windings serving as a short-circuited secondary. When started in this way such a machine will run up to synchronism without increase of voltage, and may be locked in step by excitation of the field windings.

The air-gaps and other characteristics above mentioned, are those most desirable for operation in railway work, and have been chosen as giving the best conversion and commutation. The good qualities in alternating current starting which result from them are merely incidental. The high armature reaction relatively to that of generators is highly advisable in compound-wound converters. High armature reaction, resulting in field distortion in generators, which is disastrous to commutation, has no such effect in synchronous converters since the field distortion of the direct-current output is always balanced by the field distortion of the alternating-current input. Increase of armature reaction causes a reduction of the lagging or leading currents set up by a given percentage difference of the field strength from the proper value for unity power-factor. Machines of these characteristics will stand a most surprising departure from proper field excitation when the increased heating pointed out above is considered. This feature is advisable for machines left in the charge of suburban railway station agents or other unskilled engineers in out-of-the-way sub-stations. In extreme cases, machines of these characteristics will operate on the usual low load-factor of interurban service with no shunt-field excitation whatever, as has been proved in several cases by mistakes in connecting up the field windings, mistakes not discovered until after a considerable period of operation. Other things, including full-load efficiency, being the same, a machine of high armature reaction will have a lower core-loss than a machine of low armature reaction, and will show a higher all-day efficiency on a low load-factor such as that of railway work.

Advocates of converters with a lower armature reaction assert that machines with high armature reaction have low synchronizing power, whatever that term may mean. It is certain that machines with the characteristics above outlined, will follow without falling out of step the most violent fluctuations of speed that prime-movers can set up. One such 600-volt converter has been run with full-current output down to 50 volts. They will carry, when operating single-phase, a railway load of the usual fluctuating character of interurban service, without signs of distress. In the rough and ready service that railway converters often have to stand, it is certain that a machine with stiff fields and low armature reaction will kick out its automatic alternating current switch and go out of service more readily in case of an outside disturbance, such as a single-phase short-circuit on the alternating current lines, than will a machine with higher armature reaction. The machines outlined above do not drop out of step with direct current short-circuits when protected by the usual breakers, and the writer has never heard of a well authenticated case of one of these machines slipping a pole and continuing to run with direct-current polarity reversed, either from a direct current or an alternating current short-circuit, although this action has in one or two cases been suspected. In the matter of hunting, opinion is divided between the advisability of high or low armature reaction, but there are converters aggregating several tens of thousands of kw. capacity in service with high armature reaction even without the usual short-circuiting pole face windings.

It is interesting to compare the above minimum limit of alternating self-starting current with the minimum limit of current required for a starting induction motor before passing to the more practical field of service conditions. The torque required to start a converter from rest after a few days' shut-down may be expressed as 12 to 15 per cent. of full-load torque, the latter term representing the torque which would be set up by full-load current generated. In other words, when started as a direct-current motor, 12 to 15 per cent, of full-load current may be required, if the field strength is normal. The induction motor designed to start a six-pole converter must have four poles in order to bring the machine up to synchronism. Since an induction motor requires at least as great a current to develop a given torque at standstill as at full speed, the development of the above torque corresponds to 20 to 25 per cent. of converter full-load current input, or about one-half that required for self-starting from the alternating-current side. In other words, the advantage that the induction motor gains from design for one purpose only, is partly offset by its higher synchronous speed. With the same margin, the self-starting method should take in service about twice the volt-amperes of the other. In practice a large factor of safety in the form of a margin of voltage over that required must, of course, be allowed with either method, to cover low impressed voltage, extra friction, etc.

In actual service using this method, 25-cycle converters under 500 kw. in size, are usually started from mid-taps in the

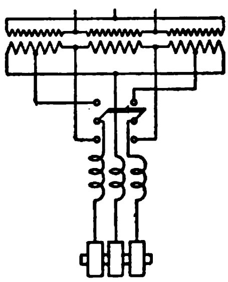


FIG. 3—Partial voltage starting connections of three-phase converter with series reactance

transformer windings, giving the converter one-half rated voltage, since it is expedient to locate a tap at the middle of the winding rather than at any other point more exactly suited to the purpose. Where reactive coils are used, these are connected in the starting circuit as shown in the accompanying diagram of connections, Fig. 3, since it is found that one-half voltage is sufficient to start such a converter through the usual 15 per cent. reactance. Early practice used a mid-tap in each of the three sides of the delta, but the change of phase when throwing from half to full voltage was found to give a greater swing, and the apparent unbalancing of the load with the connection shown was found to be negligible. The converter starting current under this condition, amounts to about one and three-quarters to twice full-load current, this being, by virtue of the compensator action of the half-voltage tap, equal to or less than full-load primary volt-amperes. A converter started in this way, runs up to synchronous speed in from 15 to 25 seconds with negligible sparking at the direct-current brushes.

It may lock in step with either positive or negative polarity to line, wrong polarity being customarily taken care of by a field reversing-switch, which closes the field for self-excitation without field rheostat in circuit, with a reversed connection for building up the machine when rotating in the direction set up by the alternating currents. The current sent by the armature through the field winding, acts against the flux induced by the alternating magnetizing current, driving this flux out in the form of magnetic leakage beween the poles. Friction under this condition drags the armature back until the electromotive force delivered to the brushes just reverses, when the field again reverses and holds the armature from falling back any further. The field reversing switch may then be safely thrown over into the normal connection, when the machine will build up with proper polarity to line. This action at starting voltage, calls for a volt-ampere input less than one-half full-load watts. When other compound-wound machines are carrying load in a railway sub-station, the polarity may be instantly corrected by closing the switch or switches which parallel the series field of the newly started machine with those already in operation. The division of direct current between the several series fields, serves as separate excitation to slip a pole of the newly started converter at starting voltage. With correct polarity and field excited, the machine may be thrown instantly from half voltage to full voltage with a momentary volt-ampere input not exceeding three-quarters rated watts, this input settling down to usual no-load value as soon as the field has time to build up.

Twenty-five cycle converters of 500 kw. and over, when fitted for alternating-current starting, are commonly equipped with tandem switches designed to connect them first to taps which will deliver to the windings one-third normal voltage. With this low voltage the reactive coils are cut out, the volt-amperes expended in the reactive coil during starting being thus saved. Two steps are necessary to pass from one-third to full voltage, since one jump would give too great a swing of current. These are commonly made by two double-throw switches connected tandem, to prevent the possibility of short-circuits. The arrangement is shown with complete connections for a six-phase converter with a three-phase reactance in the accompanying diagram, Fig. 4. With this arrangement, 25-cycle converters commonly take about two-thirds to three-quarters of rated full load volt-amperes in starting, and get up to speed in 20 to 25 seconds.

The advantages of this self-synchronizing method of starting in times of emergency, and at all times in small outlying substations, are obvious.

In that the same power is used for starting as for running without auxiliary apparatus other than switches, no reserve or duplicate method of starting is required, there being no more need of such a duplicate than (for example) for the starting of a steam engine. This results in simplifying the equipment and operation. When starting is accomplished by means of an induction motor, means of starting from the direct-current side

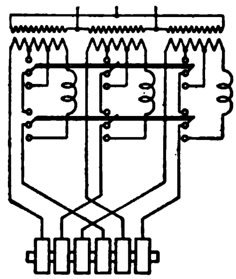


FIG. 4—One-third and two-thirds voltage starting connections of six-phase converter with diametrically connected transformers and three-phase reactance

are warranted by the helplessness of the converter in case the motor fails. The induction motor secondary has necessarily a high resistance in order to give good torque at standstill, and this resistance is usually made internal. As the motor is only intended to run for a short time starting cold, its design is cut fine, giving high densities. In cases of trouble giving several shutdowns in quick succession, it may become impossible to start the converters without waiting for their induction motors to cool down. Instances of this kind have occurred. Self-starting converters may be run up repeatedly as quickly as they will slow down for an indefinite period without overheating.

A six-phase machine will start with two diameters and will operate with reduced capacity on two diameters, just as a three-phase machine will operate on open delta. Incidentally, this is a slight advantage of the six-phase machine over the three-phase, in that when a transformer fails, it can be readily cut out of service in the case of a six-phase machine, whereas, in two cases out of three, with a three-phase machine, it is necessary to make several cable alterations to preserve the alternating current starting features.

When starting with alternating currents directly applied, it

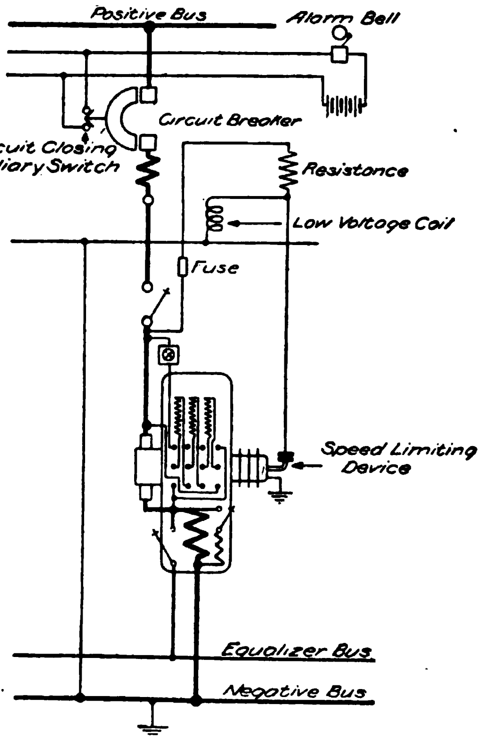


FIG. 5—Direct-current connections of railway converter arranged for self-starting; showing four-pole, double-throw field-reversing break-up switch and series-shunt switch

is advisable to open the field circuits, as if these are left closed, considerably greater currents are required, and the starting torque is reduced. The shunt field circuits should be opened at several places, otherwise the induced voltage may be too high. The shunt-field reversing switch above mentioned, and field break-up switch being combined, no other means of opening the field should be provided, so that if this switch is left closed, the shunt field will be short-circuited through the armature, and no high voltage can result. The equalizing connections of the series field must of course, be opened during starting, and the shunt for the series field is also provided with a switch to be opened at this time to cut down the draught of current. This shunt, as customarily supplied, following the established precedent of the days of engine-driven generators, seems with its

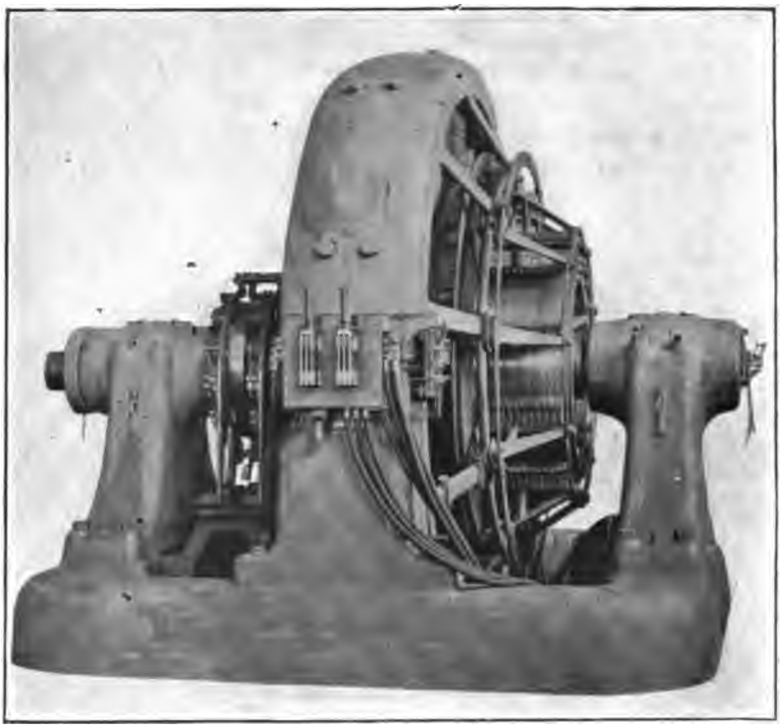


Fig. 6—1500-kw., 25-cycle, six-phase railway converter of high armature reaction, showing field-reversing, equalizer, and series-shunt switches

switch to be a rather useless appendage, since it is rarely, if ever, used to adjust the compounding; and it is useless for adjusting the division of load fluctuations, in that its usefulness for this purpose depends altogether on bad equalizing, which does not usually exist in compact sub-stations.

When a number of converters on one system are started simultaneously, as after a shutdown, the starting currents are sufficient to lower the voltage considerably, especially if but one generator is in service. The lowering of voltage at this time is, of course, immaterial, unless sufficient to prevent the converters from starting, no instance of which has ever come to the writer's knowledge · It is customary on many railroads to connect up all alternating-current feeders at once after a shutdown, allowing the sub-station attendants to run up the converters as rapidly as possible. The lack of perfect synchronism between the at-

FIG. 7—Series reactance and one-third and two-thirds voltage starting switches for 1000-kw. converter

tendants' movements and the rapid acceleration of the converters coming up to speed in a few seconds, is sufficient to avoid an overdraught of current, even in extreme cases. At other times, that is, when the system is carrying load, the starting of a converter does not cause any disturbance which it is possible to distinguish on any part of the system, from those set up by the ordinary fluctuations of railway load.

A synchronous converter is a better self-starting machine than is a constant-speed induction motor of high efficiency and the same frequency, size, and speed. Such a motor with short-circuited secondary, takes in service for starting a volt-ampere input equal to an overload of 25 to 50 per cent. Some engineers who would not hesitate to arrange for the self-starting of such an induction motor, do not favor the self-starting of the corresponding synchronous converter, so great has been the misunderstanding of this subject.

In several cities of this country converters of the largest sizes are regularly started from the alternating current side, their supply of power coming from lighting systems supplying lights through other converters from the same alternating current network. In one city, converters of 1000 and 1500 kw. capacity are supplied from a system carrying a lighting load, and although these converters are equipped with induction motors for starting purposes, the starting is usually accomplished by the above described self-starting means.

Compounding of converters Although it is generally known that converters cannot be compounded without reactance in the circuit, and that the smaller the reactance the greater must be the strength of the series field for the same regulation, few engineers have any idea of the best values of reactance and series field strength, or the shape of the compounding curve with different values of resistance and reactance; or, what is more important, the best transformer ratio and best setting of shunt field rheostats.

Before taking up the rather complex reactions with both resistance and reactance in circuit, a mental picture of the effect of reactance alone, in the simplest case, can be obtained from the vector diagram Fig. 8, where the large triangle represents a three-phase voltage, as delivered to a three-phase reactance and through this to a converter, the voltage of which is shown as a circle. At no load, and neglecting losses, assuming a shunt-field excitation for unity power factor; that is, no leading or lagging current, there is no drop in the reactance owing to the absence of any current, and the impressed voltage is delivered without change, the inside circle representing the converter voltage under this condition. At full load the energy current flowing through the reactance gives a reactive drop at right angles with the electromotive force delivered to the converter, which for one phase may be represented by the line $A\,B_1$. The impressed voltage of one phase may be represented by the line $O\,A$, the voltage delivered to the converter (if the converter is shunt wound) by the line $O\,B_1$, with which $A\,B_1$, the reactance drop, makes a right angle, since the current is assumed to be in phase with the converter or delivered electromotive force, and the reactance drop is normal to the current. If now the converter is compound wound, the leading current drawn by the increased

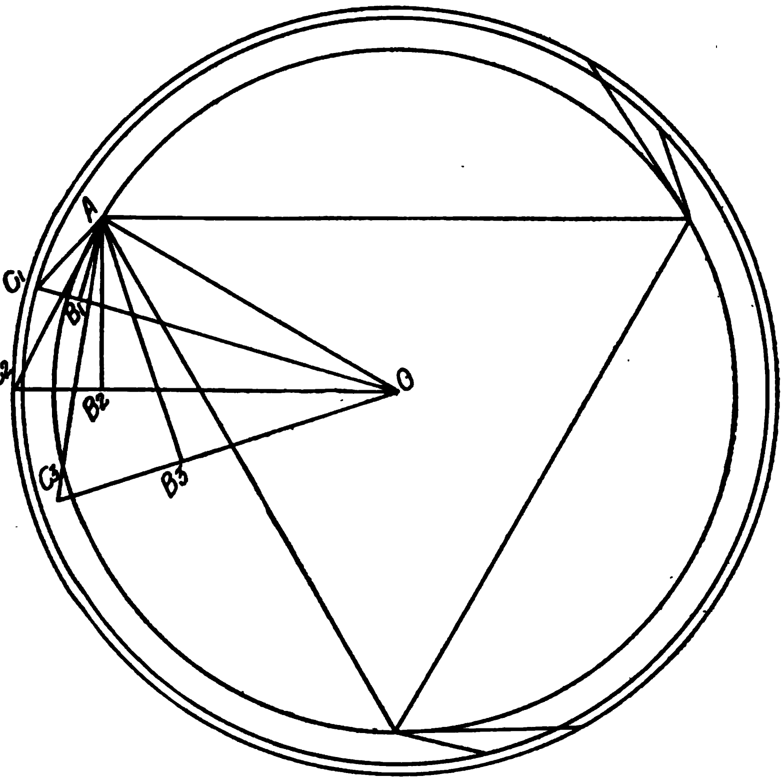


FIG. 8—Illustrating effect of reactance on voltage of compound-wound converter

field strength at full load gives a reactive drop B_1C_1 which increases the delivered electromotive force from the value $O\,B_1$ to $O\,C_1$, the reactive drop (which is really a rise) of the resultant current being $A\,C_1$. The middle circle drawn through the point C_1 and corresponding points of the other phases then represents the converter electromotive force at full load, the collector ring represented by the point C_1 lagging behind the impressed electromotive force by the angle $A\ O\ C_1$ and being pushed out (so to speak) by the reactive drop of the leading current from B_1 to C_1.

With greater reactance, the lines $A\ B_1$ and B_1C_1 both become longer, always retaining the same proportion, since one is caused by the energy current and the other by the magnetizing or leading current, both of which are unaffected by the reactance in circuit, neglecting variation of shunt field. Thus with twice the reactance, the resultant reactive drop increases to $A\ C_2$ and with three times the reactance to $A\ C_3$, the triangles $A\ B_2\ C_2$ and $A\ B_3C_3$ being exactly similar to $A\ B_1C_1$.

It may be seen that increasing reactance enlarges the delivered voltage up to a certain limit, after which it diminishes, since the increasing drop of the energy current $A\ B_3$ diminishes the other side $O\ B_3$ of the right angle triangle $O\ A\ B_3$ with fixed hypothenuse $O\ A$ so rapidly that the effect of the compounding B_3C_3 can not increase rapidly enough to make up for it.

With greater series field strength and fixed reactance the component B_1C_1 increases at the expense of reduced power factor, $A\ B_1$ remaining constant. Since the resultant drop $A\ C_1$ is at right angles with the current it may readily be seen that the more this drop departs from a right angle with the delivered electromotive force $O\ C_1$ the worse the power-factor becomes.

If we assume that with changing load the leading current increases in direct ratio with the energy current giving a constant power-factor and constant angle between the reactive drop and the delivered electromotive force, the effect of overloads becomes in this simple case the same as that of increased reactance, an overload of 100 per cent. with the initial reactance doubling the reactive drop of the energy current from the full load value $A\ B_1$ to $A\ B_2$ and that of the leading current from $B_1\ C_1$ to B_2C_2 giving again a resultant drop of AC_2. In general, with any value of reactance and series field, the compounding curve is not straight, but droops on the higher loads. This can be shown by reference to the same figure, taking an extreme overload to make the drop obvious. Three times full-load current gives a reactive drop $A\ C_3$ and a delivered electromotive force $O\ C_3$ which is less than the full load or 100 per cent overload values $O\ C_1$ and $O\ C_2$ owing again to the shortening of $O\ B_3$ as $A\ B_3$ lengthens. For the same reason it will be noted that the rise of voltage from no load to full load is greater than that from full load to 100 per cent. overload. In practice, other things, such as magnetic leakage and weakening shunt field, increase the droop. It may be mentioned that $O\ A\ C_1$ represents fairly well ordinary service conditions at full load, the effect of resistance being to bring C_1 back to the inside circle. The saturation of reactances cuts down the overload triangles to smaller figures than here shown.

Over-compounding has gone out of fashion, partly thanks to the low power-factors accompanying over-compounding with converters supplied from a system with considerable alternating current drop, and partly due to the connection of converter sub-stations directly to trolley lines, without feeder drop at

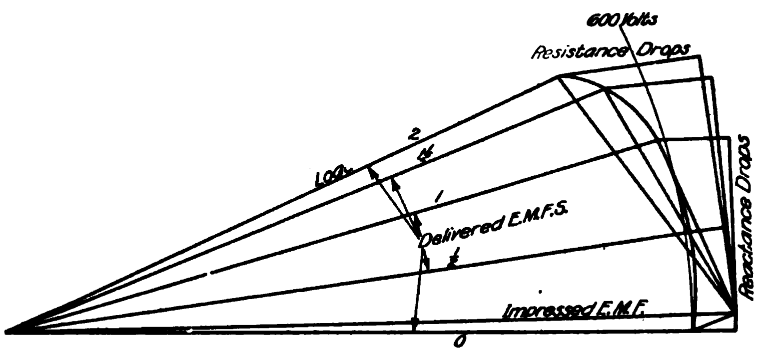


FIG. 9—Diagram showing relations of impressed and delivered electromotive forces for various loads with 10% resistance, 25% reactance, and 50% series field. Arc of circle 600 volts. Irregular curve delivered volts. Note reactance drops from half load to twice full load at right angles approximately with impressed electromotive force showing approximate unity power-factor of input

their nearest points, both of which factors have led to a more rational consideration of direct current feeder drop. It is now considered advisable to have the maximum voltage applied to the car equipments when near the sub-stations fixed, and not dependent on over-compounding caused by their own or other loads.

In accordance with the established custom of assuming a drop of 10 per cent. at full load, which custom has prevailed in all constant potential work since the earliest days of the incandescent lamp, converter equipments are commonly assumed to be called upon to give flat compounding at the direct-current side with a total resistance in the alternating current circuits of 10 per cent., including transformer and converter resistance, constant potential being assumed back of this 10 per cent. resistance, usually at the power house.

To reduce the average heating, compound converters should have their shunt fields so adjusted as to draw a considerable lagging current at no load. This does not materially change the compounding. For best operation under fluctuations from no load to 100 per cent. overload, the best shunt field setting would be such as to give unity power-factor at some point well above average load such as about full rated load. This would give about one-half to three-quarters full-load current lagging at no load, according to the series field strength of the converters, which is impracticable in service, as substation attendants would not operate in this way, but would increase the direct current voltage. A more practical assumption is unity power-factor at one-half rated load, that is the same amount of lagging current at no load as leading current at full load. It can be shown mathematically (see Appendix 2) that for flat compounding between no load and full load, with unity power-factor midway, minimum wattless current at no load and full load, *i.e.* best power-factors, are obtained with a reactance equal to the resistance multiplied by the square root of one plus two divided by the percentage resistance drop. With 10 per cent. resistance this calls for 46 per cent. reactance, and a wattless current at no load and full load equal to 23 per cent. of full-load energy current.

This compares with existing established practice as follows: A large number of railway converters in this country are equipped with series fields of such strength (when shunted) as to balance one-half full-load armature ampere-turns at full load. In other words, such a converter with shunt field rheostat set for unity power-factor at zero load, will (over and above energy current) draw a leading current at full load equal to one-half full-load current. In line with the above argument it will be assumed that these converters have their rheostats so set as to draw a lagging input equal to one-fourth full load current at no load, which will give unity power-factor at approximately one-half load, and a leading component equal to one-fourth full-load current at full load.

Many of these converters are equipped with 15 per cent. reactive coils; that is, reactive coils which, with full-load current, will show across the terminals of the winding in each phase

15 per cent. of the voltage of the circuit in which they are connected. Assuming about 5 per cent. reactance in the converter (high armature reaction) 3 to 3.5 per cent. in the transformers, and 1.5 to 2 per cent. in line and cables, the total reactance in circuit to the direct current brushes amounts to 25 per cent. This represents about the maximum reactance in commercial use in this country. It will also be assumed that constant potential is delivered to this circuit with a total resistance drop including that of transformers and converter to the direct current brushes of 10 per cent. at full load.

Assuming 600 volts as the no-load pressure, the compounding for both the best value of reactance and this representative case is given in the following table, the figures being calculated by the method of complex quantities, due allowance being made for magnetic leakage and saturation of reactances from test records, also for variation of shunt fields with voltage.

POWER-FACTORS AT CONVERTERS AND DIRECT CURRENT VOLTS.

10% resistance			Unity power-factor at half load			
	46% reactance 46% series field		25% reactance 50% series field		12.5% reactance 80% series field	
Load	Volts	Power factor %	Volts	Power factor %	Volts	Power factor %
0	600	19	600	16	600	10
0.25	614	93	605	90	601	82
0.5	619	100	605	100	599	100
0.75	615	99	602	99	597	97
1.00	600	98	596	97	593	93
1.5	540	97	567	95	576	89
2.0	475	97	533	94	550	88

All power-factors below one-half load represent lagging current, while those above represent leading current.

The power factors *at the converter* are also given for the various loads, these being independent of the reactance in circuit, and dependent only on the relation of the wattless and energy inputs drawn respectively by the field excitation and the load. While the power-factor *of the input* of the 46 per cent. reactance case varies with the load, that of the input to the 25 per cent. reactance and 50% series field combination is above 99% from one-half load to one-hundred per cent overload, the leading effect of the series field almost exactly balancing the lagging effect of the reactance between these limits.

The drop in pressure of the theoretical case on overloads puts

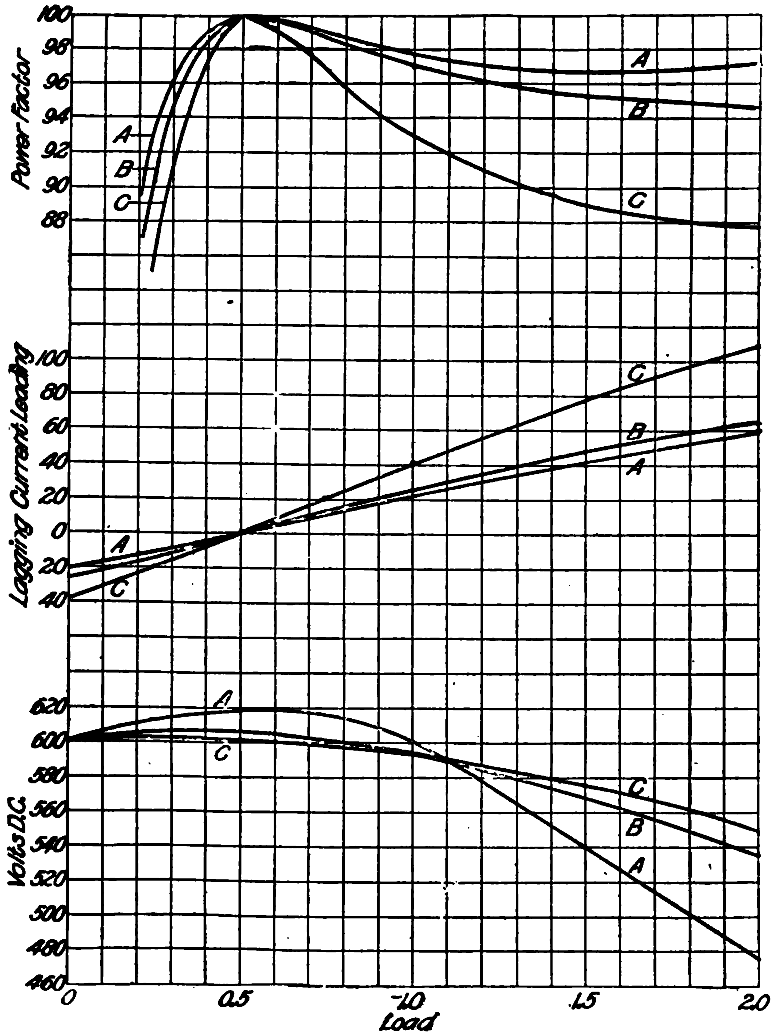


Fig. 10—Compounding curves, wattless component curves in terms of full-load current and power-factor curves of converters with 10% resistance and, A, 46% reactance, 46% series field; B, 25% reactance, 50% series field; C, 12.5% reactance, 80% series field

it out of consideration for practical service, but that of the 25 per cent. reactance case is, in the writer's opinion not objectionable, as it enables a converter to shirk its work rather than trip its breaker when overloaded, and tends in a properly designed network to throw excessive overloads to neighboring sub-stations. It also eases the blow of a short-circuit.

When separate reactive-coils are not used, dependence being placed on the internal reactance of converter, transformers and line, the total reactance of the circuit may be assumed to be as low as one-half that given above, or about 12.5 per cent., especially where converters of low armature reaction and consequently of low internal reactance are used. This represents about the minimum reactance in commercial use. To get the same regulation between no load and full load with this smaller reactance, the series field of the converter must balance an armature reaction of over 80 per cent. instead of 50 per cent; that is, a leading component equal to more than 80 per cent. of full load current must flow in the armature to balance the effect of the series field at full load. Assuming again that the shunt field is so adjusted as to give unity power-factor at half load; that is, 40 per cent. of full-load current lagging at no load, the table gives the power-factors for this case at various loads. It will be noted that while the 25 per cent. reactance gives much better regulation and only slightly lower power-factors than the best theoretical reactance, the 12.5 per cent. reactance gives much lower power-factors, the effects of which can be imagined from the heat distribution curves given in the first part of this paper.

It will be noted also that the small reactance and more powerful series field give a somewhat better regulation on heavy overloads, but it is doubtful whether this regulation can be actually reached, as it calls for heavy leading currents which it is difficult to obtain even with a machine of low armature reaction; for example, at twice full load, over full-load leading current is required. Under this condition the armature reaction is opposed to the field flux, tending to cause magnetic leakage. In this case the power-factor of the system varies with the load, as the series field greatly outweighs the influence of the reactance.

The above discussion disregards the reactance and resistance of the generators on the score that the fluctuations of load on one sub-station will not disturb the main station voltage of a large system, and will be compensated by hand adjustments of the field rheostats on a moderate size system and by automatic means on a small system, so that constant potential at the main station bus-bars may be assumed.

Records of compounding tests under similar conditions check these results as closely as might be expected, consistent results from tests under service conditions being unobtainable owing to fluctuations of other loads, voltage, etc.

Such a high reactance as the maximum above calculated might give instability, but no such case has ever been noticed with 25 per cent. reactance, even with high resistance drops and converters of high armature reaction without pole-face windings. In one case of extreme hunting due to excessive line drop, the writer inserted in circuit a reactance of 20 per cent., the result being a slight increase of the angle of oscillation of the armatures

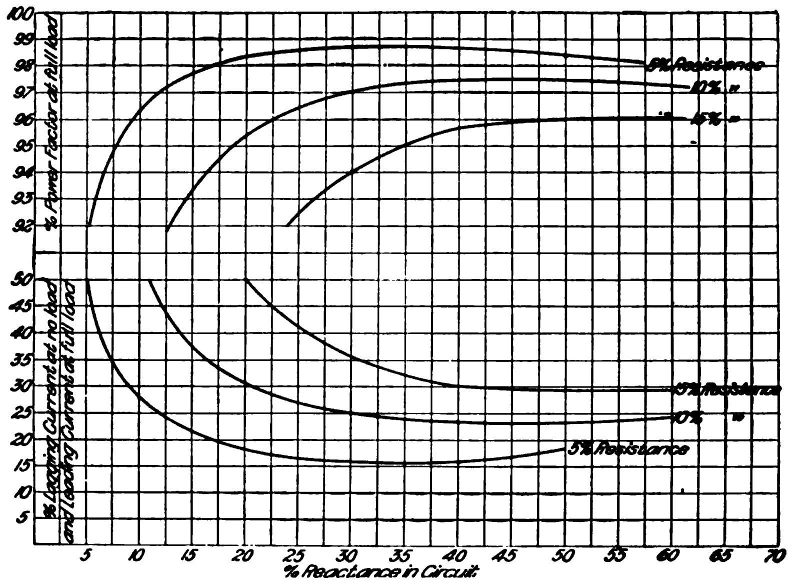


Fig. 11—Curves of wattless components and power-factors for flat compounding no load to full load with varying reactance

as noted by a stroboscopic method; but there was a great reduction of the periodicity of the oscillation, and of the effect on the voltage, due to the variable input of energy to the converters and consequent variation of line drop.

In actual practice such good results in power-factors are not obtained owing to lack of instructions concerning the setting of field rheostats. Transformers for compound converters are almost invariably designed to give a secondary voltage adapted to the ratio of conversion at no-load unity power-factor; in other words, if the ratio of conversion is 0.62, calling for 370 volts to give 600 direct voltage, the transformers are designed to give 370 volts instead of 390 volts or more, as they should do to deliver normal direct voltage with proper lagging current at no load. Even where transformers of proper ratio are in use, or the alternating voltage is sufficiently high, the tendency of human nature to push up the direct voltage tends to cut out the no-load lagging component and lower the power-factor on load.

This is particularly the case where power-factor indicators are installed in the circuits of the converters. Even where these instruments are properly connected, which frequently is not the case, the natural tendency of the attendants is to bring up the excitation on starting a converter until the power-factor indicator shows approximately unity power-factor. These instruments are frequently so connected as to show the power-factor at a point with considerable reactance between it and the converter. In this case their readings are absolutely misleading, an indicated power-factor of 97 per cent. leading (for example) often meaning a power-factor at the converter of 90 per cent. or less. While it may be possible to get attendants to set their rheostats for proper voltage, if this does not call for more than 25 per cent. of full-load current at no load, which does not make much of a showing on an alternating current ammeter capable of reading twice full load, 40 per cent. is much more difficult.

In city work with comparatively small fluctuations, converters of the above series field characteristics, have been installed, but without series reactive coils, the argument being that these are unnecessary on comparatively steady loads. It would be much more satisfactory to omit the series winding and install the reactance, in order to give the attendants an opportunity to adjust their voltage by hand with smaller wattless currents.

In general, the writer contends that best practice, with systems approximating 10 per cent. resistance, is the increase of the natural reactance of the circuits to approximately 25 per cent., and the use of a series field of such strength as to balance about one-half full-load armature ampere-turns, with transformer ratios such as to give normal direct voltage with at least one-quarter full-load current lagging at no load; converter field rheostats to be set for normal direct voltage regardless of power-factor, and main station voltage to be kept constant at such a figure as will give unity power-factor at and above such a load as gives an average of one-half load or more to the converters.

The result of existing practice is low power-factors on heavy loads, particularly with converters of low armature reaction, and more particularly in circuits of small reactance, which would probably give trouble in many cases, especially with three-phase converters, but for the low load-factors of interurban railway work and the heavy overloads for which the converters are designed.

APPENDIX I.

If I = direct current per path in armature of converter

and α = angle in electrical degrees between middle of one section (between collector taps) and plane of commutation, assumed neutral

and ϕ = angle of lag between current and counter electromotive force, alternating current

and β = angle between middle of section and any bar of resistance, r.

Then alternating current per path in winding of three-phase machine

$$= I \frac{8 \sin (\alpha + \phi)}{3\sqrt{3} \cos \phi}$$

Resultant current $= I \left[1 - \frac{8 \sin (\alpha + \phi)}{3\sqrt{3} \cos \phi}\right]$

Heating of bar $= I^2 r \left[1 - \frac{8 \sin (\alpha + \phi)}{3\sqrt{3} \cos \phi}\right]^2$

Ratio of heating to that of same load mechanically generated $= \left[1 - \frac{8 \sin (\alpha + \phi)}{3\sqrt{3} \cos \phi}\right]^2$

$$\text{Average ratio} = \frac{1}{\pi} \int_{\beta}^{\pi + \beta} \left[1 - \frac{8 \sin (\alpha + \phi)}{3\sqrt{3} \cos \phi}\right]^2 d\alpha$$

$$= \frac{59}{27} - \frac{32 \cos \beta}{3\pi\sqrt{3}} + \frac{32}{27} \tan^2 \phi + \frac{32 \tan \phi \sin \beta}{3\pi\sqrt{3}}$$

similarly the alternating current per path in winding of six-phase machine $= \frac{4 \sin (\alpha + \phi)}{3 \cos \phi}$

$$\text{Average ratio} = \frac{1}{\pi}\int_{\beta}^{\pi+\beta}\left[1 - \frac{4\sin(\alpha+\phi)}{3\cos\phi}\right]d\alpha$$

$$= \frac{17}{9} - \frac{16}{3\pi}\cos\beta + \frac{8}{9}\tan^2\phi + \frac{16}{3\pi}\tan\phi\sin\beta$$

These two expressions are plotted in Fig. 1. ϕ being O in the upper curves and 15° in the lower.

Average heating of whole winding of three-phase machine

$$= \frac{2\pi}{3}\int_{-\frac{\pi}{3}}^{\frac{\pi}{3}}\left[\frac{59}{27} - \frac{32\cos\beta}{3\pi\sqrt{3}} + \frac{32}{27}\tan^2\phi + \frac{32}{3\pi\sqrt{3}}\tan\phi\sin\beta\right]d\beta$$

$$= \frac{59}{27} - \frac{16}{\pi^2} + \frac{32}{27}\tan^2\phi$$

Similarly the loss in the six-phase winding integrated between $\beta = \frac{\pi}{6}$ and $\beta = -\frac{\pi}{6}$ gives average

$$= \frac{17}{9} - \frac{16}{\pi^2} + \frac{8}{9}\tan^2\phi$$

APPENDIX II.

If E = impressed electromotive force

and e_0 = delivered electromotive force at no load

and e_1 = delivered electromotive force at full load

and i_0 = lagging current at no load

and i_1 = energy current at full load

and r, x and j have their usual values.

Then leading current at full load $= -i_0$ since the wattless current is assumed same at zero as at full load.

At no load $E = e_0 + i_0 x + j i_0 r$

At full load $E = e_1 + i_1 r - i_0 x + j(i_0 r + i_1 x)$

Expanding these two quantities to get absolute values (when $e_0 = e_1$ since the delivered voltage is assumed to be the same at full load as at no load) gives

$$i_0 = \frac{i_1 r}{2x} + \frac{i_1^2 r^2}{4 e_0 x} + \frac{i_1^2 x}{4 e_0}$$

This expression is plotted in Fig. 11.

Differentiating this expression with respect to x to obtain the value of x which give the lowest value of i_0 gives

$$\frac{d i_0}{d x} = \frac{-i_1 r}{2 x^2} - \frac{i_1^2 r^2}{4 e_0 x^2} + \frac{i_1^2}{4 e_0} = 0$$

$$x = r\sqrt{\frac{2 e_0}{i_1 r} + 1.}$$

DISCUSSION ON "THE NON-SYNCHRONOUS GENERATOR IN CENTRAL STATION AND OTHER WORK," "SOME DEVELOPMENTS IN SYNCHRONOUS CONVERTERS," AND "SOME FEATURES OF RAILWAY CONVERTER DESIGN AND OPERATION." NEW YORK, FEBRUARY 14, 1908.

C. F. Scott: The three papers presented to-night deal with alternating-current apparatus and show the wide variations in methods which are practicable with alternating current but not with direct current.

When a new machine or method is proposed, it frequently happens that it may accomplish the specific purpose for which it is intended, but it may involve some incidental feature that renders the whole inoperative or inadmissible. Mr. Waters not only describes the induction generator but points out its various advantages over synchronous generators in construction and also its marked advantages in operation. Instead of introducing objectionable characteristics, it presents many points of advantage—reduced current on short-circuit, a smooth wave-form, and damping action due to the short-circuited element, which exerts a steadying and soothing effect throughout the whole system, that tends, in turn, to prevent hunting and surges. The paper indicates that there should be a considerable commercial field in which this type of generator will have an important application.

Mr. Stone presents six methods of voltage regulation of synchronous converters. It may be noted that the alternating-current booster may be provided with either a shunt field winding or a series field winding, or both. If a series field winding carry the current from the synchronous converter, then the compounding may be effected automatically by a practically straight-line law over a considerable range.

A comparison of the relative characteristics of the several methods of voltage regulation is of interest. In several a mechanical adjustment of the apparatus is necessary. In the case of the transformer with loops, the connection must be shifted from one loop to another. In the induction regulator mechanical rotation must take place. The reactance involves no such adjustment. In the methods in which field current is adjusted, the windings may be either shunt windings for hand control or series windings for automatic control. Auxiliary automatic control apparatus can, of course, be applied for operating rheostats, regulators, and the like. The power-factor; that is, the ratio between true and apparent watts, varies when reactance is used, or the methods in which the field poles are divided into parts which are unequally excited. The power-factor is practically unaffected when transformer loops, induction regulators, or boosters are employed. The wave-form is not affected unless it be in those cases where the field poles are divided into two or more parts. The range of voltage variation is relatively small with reactance. It is probably small with the methods in which the field poles are divided into parts, unless considerable variations in power-factor or wave-form are admissible. The range may be very large when other methods are employed. These characteristics are brought together in the following table:

Method	Inherently automatic	Hand adjustment	Power-factor	Wave-form	Range
1. Transformer loops.......	—	Yes	O.K.	O.K.	Large
2. Reactance.............	Yes	Yes	Variable	O.K.	Small
3. Induction Regulator.....	—	Yes	O.K.	O.K.	Large
4. Booster................	Yes	Yes	O.K.	O.K.	Large
5. Woodbridge............	Yes	Yes	Variable?	Variable?	Small?
6. Burnham..............	Yes	Yes	Variable?	Variable?	Small?

Paul M. Lincoln: The scheme proposed by Mr. Woodbridge for changing the direct voltage of a synchronous converter, as well as the modification proposed by Mr. Burnham, is ingenious, but I believe that Mr. Stone's descriptions are altogether too brief to be satisfying to the engineer who contemplates making use of them. At the time Mr. Woodbridge's device was originally proposed, considerably over a year ago, I became familiar with an analysis of the scheme; this analysis seemed to show that the objections to the use of such a scheme outweigh the advantages. A repetition of this analysis within the last month leads to the same conclusion. Some of the steps in this analysis may be of sufficient interest to reproduce in this discussion.

Wave-form. The first question that arises when contemplating the use of this split-pole converter is its effect upon wave-form. These questions might naturally be put as follows: will the wave form of the split-pole converter depart materially from a sine wave? If so, how much will be the departure? Will such deformation, if it occur, have any bad effect upon the converter itself or upon any part of the system to which the converter is connected?

The first two questions are probably best answered by a series of curves which were prepared in the course of the above mentioned analysis. It is well known that with a given field form, the distributed winding of a converter gives rise to an electromotive force wave-form which is subject to quite exact determination. The division of the converter field into sections, and the provision of means to excite these sections independently of each other, gives control over the field form and therefore over the alternating-to-direct voltage ratio. As the field form changes, however, the electromotive force wave-form of the converter also changes. To what extent this takes place for certain assumed field forms is indicated in Figs. 1 to 7. Figs. 1, 2, and 3 show what may be expected of a converter with its pole divided into three sections, and Fig. 4, 5, 6, and 7 what may be expected with a pole of two parts.

Fig. 1 shows, first, six possible field forms; secondly, the electromotive force wave-forms that these field forms give rise to; and thirdly, the sine wave equivalent to the determined wave-form. The wave-forms in this series, as well as all the others, are those across an electrical diameter, in other words, they are the wave-forms that would be taken across opposite rings of a six-phase or a two-phase converter. With a field form other than a sine, the wave-form across an electrical diameter deviates from sine form less than that across any chord. It gives, therefore, the most favorable condition so far as deviation from sine form is concerned. The narrower the band of conductors the more closely will the electromotive force wave-form approach the field form. A single conductor, for instance, will give rise to an electromotive force wave-form exactly similar to the field form.

The figures at the right indicate, first, the per cent. variation in direct voltage over that which would be obtained with an electromotive force wave of sine form; secondly, the deviation in the resultant electromotive force wave from its equivalent sine wave. The sine deviations are calculated according to Institute rules.

Fig. 1 assumes a three-part pole with all three parts equal, and shows the variations through which the converter field must be carried to vary the direct voltage from +13 per cent. in the lowermost figure to —15.3 per cent. in the uppermost. The first condition entails a deviation from the equivalent sine of 74 per cent. and the second of over 23 per cent. The direct-current variation can be carried still further by further deforming the field, but at the limits given in this series the field strength at maximum direct-current variation is more than double that at minimum direct-current variation. Probably no converter designer would wish to consider a further field deformation.

Fig. 2 shows what may be expected if the outside sections of the field pole are reduced from about 33 per cent. to about to 20 per cent. each of the total pole area. The direct-current variation in this series is carried from 12.8 per cent. plus to 50.8 per cent. The first condition entails a sine deviation of about 32 per cent. and the last 50 per cent. Here again the field deformation and relative field strength are carried to an extreme at the limiting conditions.

Fig. 3 shows what may be expected if the middle section of the pole is made considerably narrower than the outside sections, a condition the reverse of that in Fig. 2. In this third series the middle section is about 20 per cent. of the total pole width. The limiting direct voltage values in this series are 8.2 per cent. plus, entailing 39 per cent. sine deviation, to 6.5 per cent. minus, entailing 12 per cent. sine deviation.

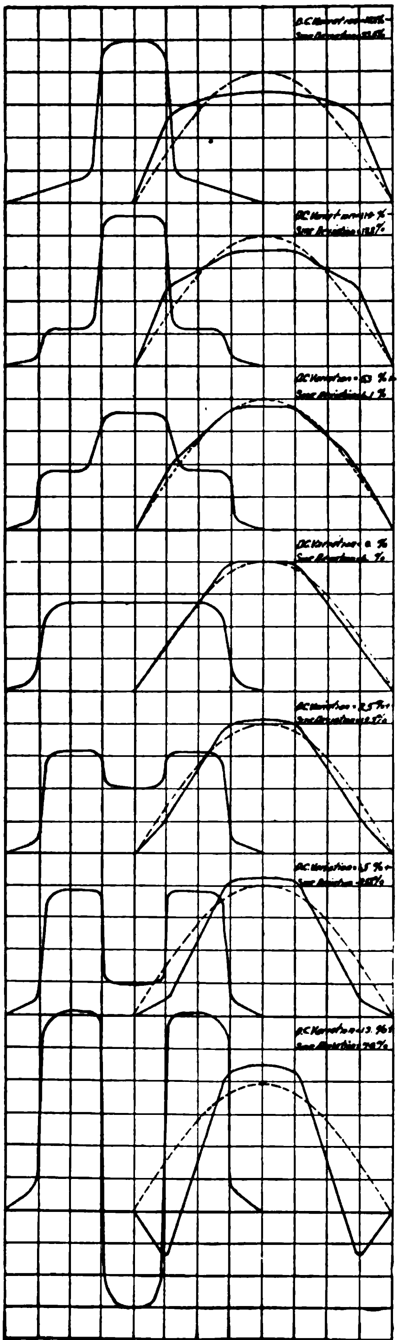


Fig. 1

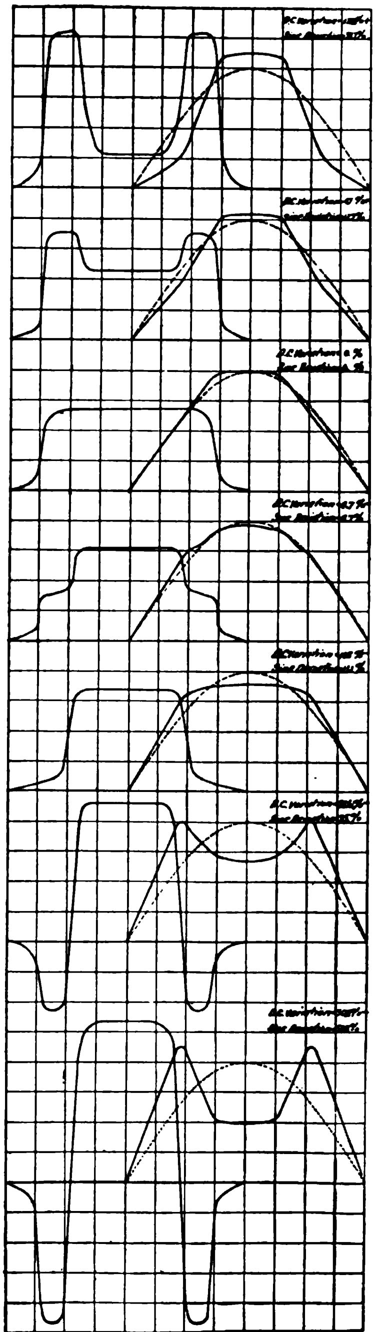


Fig. 2

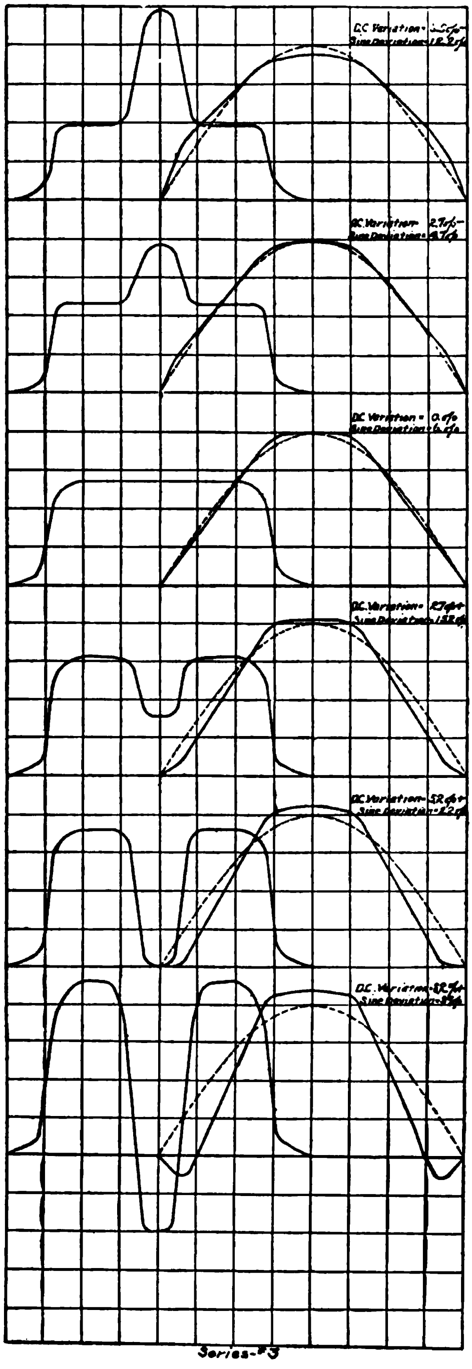


Fig. 3

Considering the three-part pole proposition as a whole, we find that to obtain a given direct voltage variation there is entailed a deviation from the equivalent sine wave of at least as great a per cent. as the direct-current variation, and for most conditions a deviation of two or three times as great.

Fig. 4 shows what may be expected with a two-part pole, the two parts being of equal area. In this series the direct-current variation is carried from 0.2 per cent. plus, to 68 per cent. minus, the former condition having a wave-form fairly close to a sine while the latter deviates over 30%. It will be seen in this series, as well as in all others dealing with two-part poles, that a good wave-form is obtained only at the upper range of direct voltage. The mid-voltage position has a sine deviation of at least 25 per cent. and the minimum voltage is not much worse. This is a characteristic difference between the three-part pole and the two-part pole. In the three-part arrangement the mid-voltage position can be made to have a wave fairly close to a sine form, while in the two-part pole arrangement the mid-voltage position has a deviation much greater than half that for minimum voltage. However, this is about the only advantage the three-part pole has over the two-part pole.

It will readily be seen from an inspection of curves in No. 4, that the minimum direct voltages are obtained by an arrangement of field which corresponds closely to shifting the brushes of an ordinary converter forward or backward until the direct voltage between them is reduced the required amount. Instead of moving the brushes, the same effect is obtained by reversing a part of the field. In this series the direct voltage might very easily be carried down to zero with not very much additional deviation from a sine wave.

Fig. 5 shows a series with the pole face divided in 70 per cent. and 30 per cent. sections instead of equal sections. The field deformation in this series is carried to such a point as to give a direct-voltage variation of about 20 per cent. each way from the mid position. The maximum deviation from sine form occurs, as pointed out above, at the minimum direct-current position and is about 25 per cent. The mid direct-current position entails a sine deviation of between 15 and 20 per cent.

Fig. 6 is worked out for a condition of approximately 15 per cent. direct-voltage variation each way. The maximum sine deviation is 20 per cent., and at the mid-voltage position a little less than 15 per cent. The small section of field is about 20 per cent. of the total in this case.

Fig. 7 is worked out for a direct-current variation of about 10 per cent. each way and shows a maximum sine deviation of 15 per cent. and a little less than 10 per cent. at mid direct voltage. The small pole horn is about 15 per cent. of the total pole in this case.

It is probable that the proper shaping of pole pieces may be made to give deviations from sine form somewhat less than I have worked out in this series of curves, but the very nature of the case will prevent results that are materially better. They may be worse.

It is patent from the foregoing that the user of a split-pole converter can expect very considerable departures of the converter wave from the generator wave. The percentage deviation from sine form will be considerably greater than the percentage variation in direct voltage each way from mid direct-current position when considering a two-part-pole converter. For reasons that will appear later, this form is the only feasible one. The next question is: will this deviation from sine wave have any bad effect on the converter or on the system to which it is connected?

When the wave-form of a synchronous machine is at variance with that of the system upon which it is operating, currents will flow, due to these differences in the electromotive force wave. Ordinarily there are two actions taking place to limit these circulating currents; first, the impedance of the circuit through which they flow; secondly, and by far the more important, the fact that these circulating currents tend to modify the electromotive force waves of both the generating system and the receiving apparatus. If any specific piece of receiving apparatus be of relatively small capacity, as is usual, the greater part of the modification takes place in that receiving machine. In the case of split-pole converters, this field modification due to the circulating-current action is entirely absent. In order to obtain the desired direct-voltage variation, the deformation of field and consequently of wave-form must be carried to the required point. The efforts of the circulating currents to bring back the field form to normal must be neutralized and overcome by the exciting force tending to deform the field. The only impediment in the way of these circulating currents, therefore, is simply the impedance of the circuit. On a very large system the impedance outside the converter becomes reduced very close to zero and practically the only impedance offered is, therefore, that of the converter armature itself.

Commercial considerations usually call for a direct-current variation of 10 to 15 per cent. each way from normal. The analysis already given shows that with such a direct-current range a third harmonic under maximum deviation conditions of 15 per cent. is quite possible. Mr. J. E. Woodbridge has assigned 5 per cent as the value of the reactance of the armature of a converter. For third-harmonic frequency this value will become 15 per cent. Assuming such a converter to be direct connected to a very large alternating-current system, a triple-harmonic current will result, of a volume equal to the full-load current of the converter. Still higher harmonic currents will flow, and the maximum deviation of the current wave will be still greater than that represented by the full-load third harmonic.

While not at all outside the range of possibility, the above conditions will be unusual, because on a very large system the

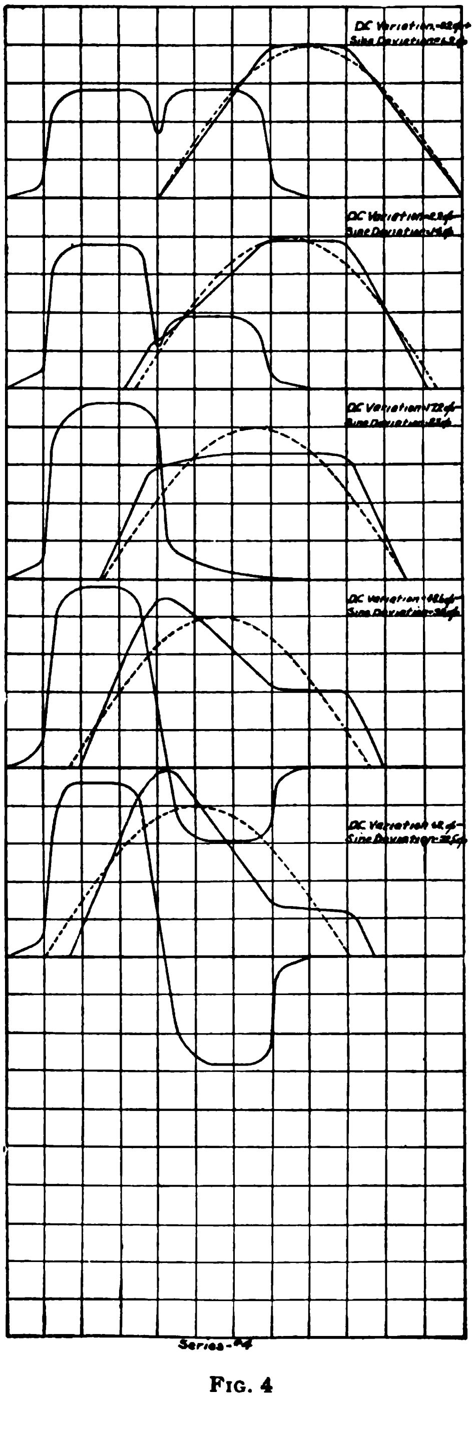


FIG. 4

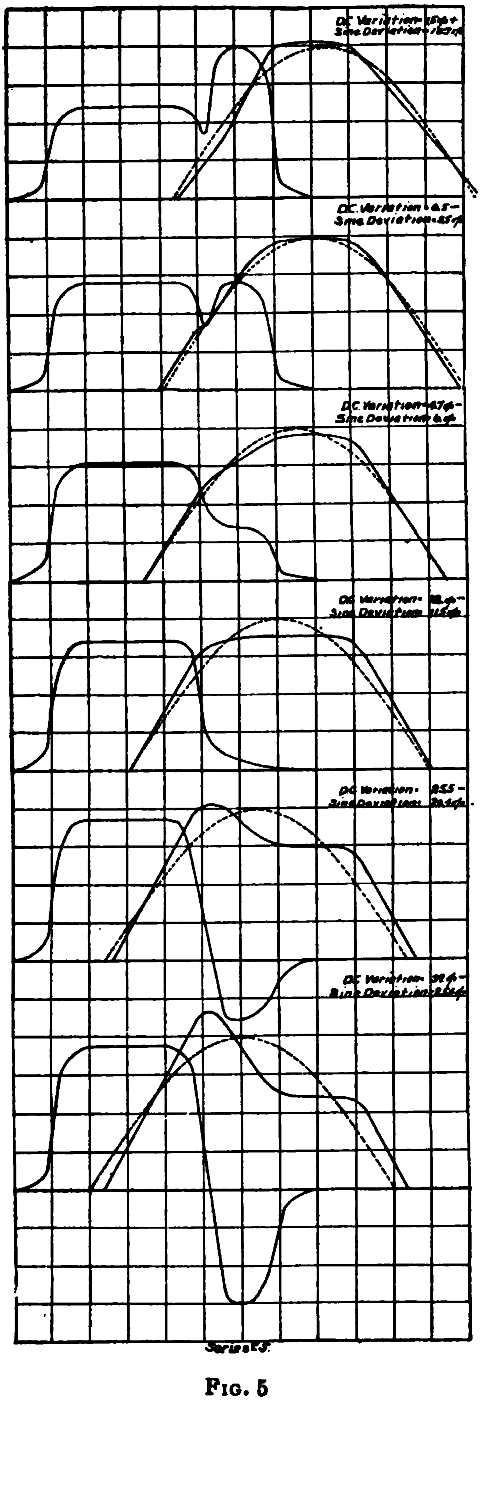


Fig. 5

converter will undoubtedly have transformers in series with it. The reactance of these transformers will assist in keeping back the circulating currents of higher harmonics. However, considering that the third-harmonic current reduces to a possible 50 per cent., it still remains a volume too large for the operating engineer to tolerate.

The above figures apply only to the behavior of one of these converters when connected to a relatively large system, where the electromotive force wave-form of the system is not perceptibly affected by the circulating currents of higher frequencies. Where the system wave-form is so affected, the circulating currents will be reduced in proportion to the modification of the generated wave-form. At the same time, however, other difficulties will be introduced, because in this latter case the wave-form of the system is largely at the mercy of the operator in charge of the split-pole converters in question. Assume a case, for instance, where one-half the load of a generating system consists of a bank of these split-pole converters, and the other half a bank of ordinary converters. The adjustments of direct voltage on the split-pole converters will, as indicated in the foregoing analysis, change the wave-form of the system. This, in turn, will cause circulating currents in the ordinary converters that will change their wave-form and, as a result, their alternating-current—direct-current ratio. We find, consequently, that the alternating-current—direct-current ratio not only of the split-pole converters on such a system is subject to modification, but also all the other converters as well. Usually such a condition of affairs would be found to be intolerable.

Power-factor. Mr. Stone says that the power-factor of these split-pole converters can be held at unity throughout the entire range of direct voltage. Before we can accept Mr. Stone's statement, a further explanation of exactly what he means is necessary. If Mr. Stone intends to convey the idea that the field of the converter can be so adujsted that the current of fundamental frequency is in phase with the electromotive force of fundamental frequency, the statement can be accepted. If, however, he means to convey the impression that the ratio of kilowatts input to kilovolt-ampere input can be held at unity, then the statement is debatable. A power-factor meter indicates the phase relation of the current of fundamental frequency to the voltage of fundamental frequency; if currents of higher frequencies and large volume are flowing, a power-factor of unity, as indicated by a power-factor meter, does not at all mean that the volt-amperes are equal to the watts. It seems probable that Mr. Stone is basing his statements upon observations of power-factor meters when used in connection with split-pole converters. The above analysis shows that it is impossible to keep the volt-amperes and the watts equal in any case where currents of more than one frequency are flowing. When a given alternating-current—direct-current ratio is to be obtained it is impossible to adjust the field strengths of one of these converters so as to eliminate these currents of higher frequencies. It is, therefore, manifestly impossible to adjust the fields so as to make unity power-factor throughout the entire range.

Capacities and costs. When considering the capacity that can be obtained from a given amount of material made up into one of these split-pole synchronous converters, we find that for equal outputs the amount of material for the split-pole is largely increased over what it would be ordinarily. Reference to the various series of curves that have been shown indicates that the field strengths in these converters at the maximum point vary all the way from 10 per cent. to 15 per cent. above that at the minimum point. to more than double that at the minimum point. Since the iron of the armature of the converter is capable of being worked only to a certain maximum magnetic density, it follows that the amount of iron in the armature must be increased with a split-pole converter in approximately the ratio of the minimum field to the maximum field. Reference to the series of curves shows that the ratios of minimum to maximum field in the three-part pole converters is very large, so large in fact that a converter built on this principle will require so much additional material as to make it an uncommercial machine. The same criticism does not apply to the two-part pole; in that case the ratio of minimum field to maximum field is roughly the ratio of normal direct voltage to maximum or minimum; in other words, if 10 per cent. machine range is required, the amount of material in the armature need be increased approximately only 10 per cent. over what it would be with an ordinary converter. This comparison is pointed out in order to show that a commercial machine can be made only when the two-part pole converter is considered.

The original Woodbridge scheme of using three parts makes so great an increase in size and cost of the resulting machine as to put it practically out of the question.

Efficiency. Considering the relative efficiencies of the split-pole converter and the ordinary type, we find that the split-pole converter increases considerably every item of loss that enters into efficiency. The field loss evidently must be considerably increased because: first, there are two parts to every pole to be excited; secondly, because the exciting tendencies of the higher harmonic frequency currents must be overcome by exciting energy put into the fields.

The iron-loss is also materially increased, particularly at the lower direct-current limits when considering the two-part-pole converter. Reference to the curves indicates that the frequency of reversals in magnetism are twice as great when obtaining a minimum direct voltage as they are with a converter of normal type. This means, naturally, an iron-loss increase in about the same proportion.

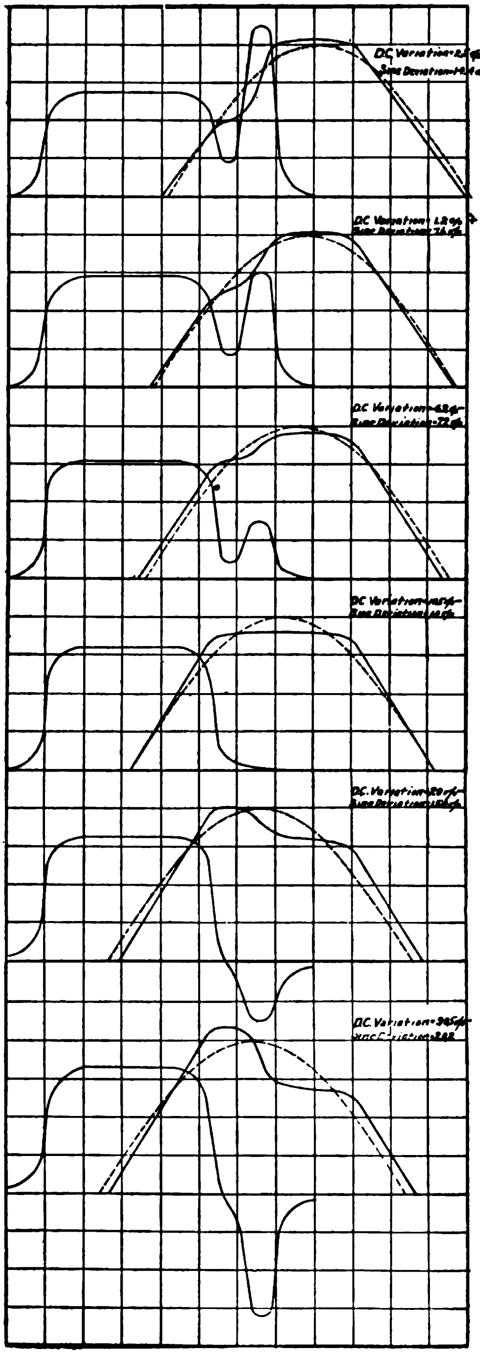


Fig. 6

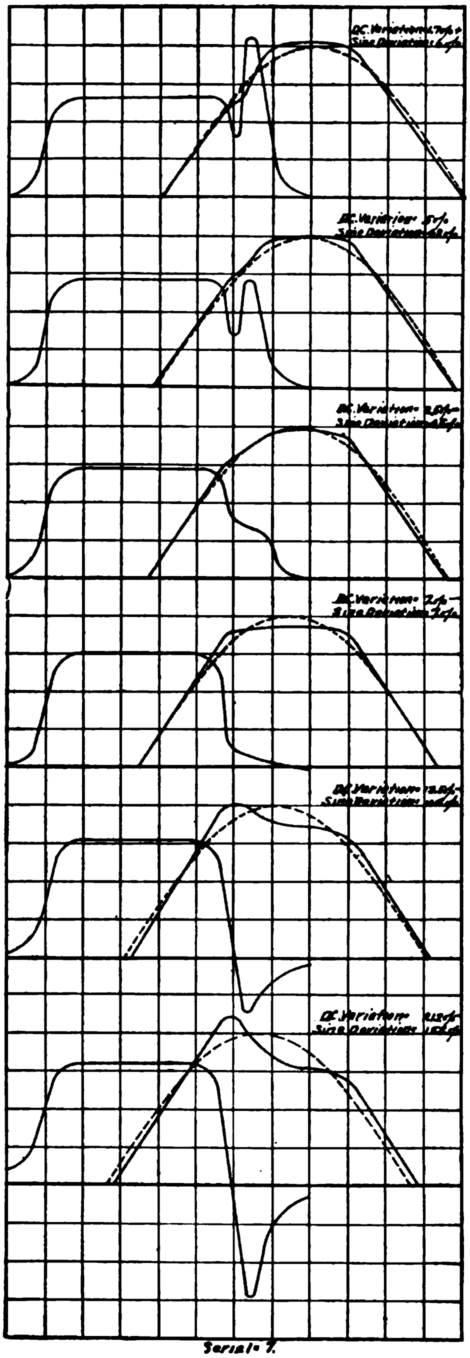


Fig. 7

On account of circulating currents of higher frequencies, the armature copper-loss is also increased above what it would be with a converter of normal type. The amount of increase of this armature copper-loss depends, as pointed out in previous paragraphs, upon the relative size of the converter, and the system to which it is connected, as well as upon the amount of deviation of converter wave from the generator wave. A number of calculations of actual cases have determined that the efficiency of these split-pole converters is as low as—in most cases lower than—the efficiency of the combined converter and separate booster which Mr. Stone describes in another paragraph.

Commutation. As mentioned in a previous paragraph, the operation of the two-part-pole converter at the lower range of direct voltages gives a result somewhat similar to shifting the brushes backward or forward into the active field. The main difference is that a notch of any desired width can be made in the pole opposite the point where the brush rests upon the commutator. When the smaller pole-horn is excited in the same direction as the main pole, the field at the point where the brush rests upon the commutator will be very close to zero. When, however, the small pole-horn is excited in a direction the reverse of the main pole-horn, the excitation of the small horn is then in the same direction as the pole just the other side of the adjacent direct-current brush. Necessarily the field at the point where the brush rests upon the commutator will change materially, depending upon whether this small pole-horn is excited in the one direction or in the other. There is no question but that commutation can be properly carried out, even with this variation of field strength at the point where the brush rests upon the commutator. It will, however, require a machine which has considerably better inherent commutating characteristics than would be the case were a converter of the ordinary type used.

Resonance. In the ordinary system, circulating currents of the higher harmonics tend to efface themselves. With the split-pole converter, however, under minimum direct-voltage conditions these higher harmonics are apt to be pushed to a point where the currents resulting from them become a very considerable portion of the total current flowing. A system which contains cables always has present the possibility of there being set up a condition in which resonance will take place. In the past, very little trouble has been experienced with resonance, for the reason, as stated above, that the higher harmonics rapidly tend to eliminate themselves. If, however, split-pole converters are used upon systems where underground cables are used to any great extent, I would not be at all surprised to find the resonance becoming of very considerable importance. In changing one of these split-pole converters from its minimum direct voltage to its maximum, harmonics of almost limitless frequencies will be set up, and their amplitudes will be constantly caused to decrease and diminish. If, therefore, there is any tendency for resonance to occur anywhere in the system, the presence of one of these converters would undoubtedly search it out and supply the proper frequency of electromotive force to make it become active. Systems, therefore, which have any great amount of underground cable should carefully investigate the possibility of such a condition arising, before deciding to adopt machines of this character.

The alternative which Mr. Stone describes; namely, a converter upon which a separate machine is mounted, having the same number of poles as the converter, has, in my opinion decided advantages over this split-pole converter, for the following reasons:

1. Its wave-form remains constant and fixed, since the added voltage is of fundamental frequency, whereas the split-pole converter is apt to set up harmonics of almost any possible frequency and of amplitudes which may easily circulate currents up to full-load values.

2. The power-factor of the booster converter can be held at unity throughout its entire range of direct voltage, whereas the split-pole converter cannot.

3. The efficiency of the booster converter is not less, but in most cases considerably more than the split-pole converter.

4. The commutating conditions of the booster converter remain fixed throughout its entire range of direct voltage, whereas in the split-pole converter, careful attention must be given to the point of commutation on account of the changeableness of the field at the point where the brush rests upon the commutator.

5. The cost of the split-pole converter are greater than an equivalent capacity of simple converter, and probably as great as the combined cost of simple converter and booster.

6. The booster converter introduces no higher harmonic voltages into the system and consequently the danger of resonance is no greater than it has been in the past. The same cannot be said of the split-pole converter.

7. All parts entering into its construction are standard. It is simply an assembly of well-known and thoroughly tried out machines of standard design.

F. G. Clark: The paper presented by Mr. Waters advances the conclusion that certain advantages possessed by non-synchronous generators are sufficient to warrant their installation in new plants in place of synchronous generators; in present plants where new units are required; in 25-cycle gas-engine installations, and for use with synchronous converters in place of large slow-speed, direct-current generators. This proposition is sufficiently radical to call for careful consideration by any one interested in power plant work.

Speaking from the standpoint of an operating engineer, I must confess to the belief that the author in his enthusiasm over advantages, some of which must be admitted as important, neglects to consider certain disadvantages which preclude the use of the non-synchronous generator in large power stations where synchronous generators are now installed. The advantages appear to be.

1. *Excellent mechanical construction.* This probably relates to the generator, and as the stator differs but little we must pass to the rotor which is described as advantage No. 2.

2. *Absence of direct-current rotating fields.* There can be no question but that this is a distinct advantage. The only reservation is the possibility of trouble due to a small air-gap on a large machine.

3. *Absence of direct-current excitation.* As we have already discussed the rotor, this can apply only to a comparison of the exciting apparatus required in each case. The claim that the excitation of a non-synchronous generator can be controlled from a distant sub-station does not appeal to me as practical. There are a few possible happenings between a sub-station and a power station which would cause either voltage-rises or interruptions chargeable to such operation. I believe it safe to say that the synchronous converter with its starting direct-current, engine-driven generator must be located at the power station.

4. *Facility for control of load by motor control of steam governor.* The synchronous generator can be similarly controlled and no advantage obtains.

5. *Unequal distribution of load between generators does not produce cross-current.* The unequal distribution of load between synchronous turbo-generators produces a flow of magnetizing current where there is a difference in excitation, and a division of current where there is a common neutral bus-bar. There is no hunting and no undue heating, therefore no practical advantage obtains.

6. *General simplicity and flexibility of operation.* The simplicity of the rotor has been acknowledged and cannot be included here. The field rheostat and the synchronizing arrangements of the synchronous generator are not required, but a reactive coil and a governor control are requisites. No practical advantage obtains.

7. *Requires less excitation than synchronous generators.* Under certain favorable conditions on a large system the total power for excitation will be considerably less for non-synchronous generators. When, however, the difference in economy due to the compensating requirements, and the operation of very large units on very light loads is taken account of, the advantage of the non-synchronous generator will not be great, or will disappear.

8. *High efficiency.* This is not an advantage unless it be relatively to a lower efficiency in other types of generators. The author admits that there must be high speed, low fre-

quency, and low voltage or the non-synchronous will not compare favorably with the synchronous generator. This limits the comparison and eliminates the advantage of efficiency except in certain particular cases.

9. *Beneficial characteristics relatively to resonance, and short-circuits.* It is claimed that the non-synchronous generator possesses the proper characteristics to prevent, or rather lacks those characteristics of the synchronous generator which promote, high-power surges, resonance, and other electrostatic phenomena. The author assumes that resonance and other electrostatic effects are produced either by short-circuits or faulty sine waves, and that the non-synchronous generator avoids these effects by depriving short-circuits of their high power, and by giving forth only sine waves.

While admitting that these are decided advantages when compared with a majority of large installations, I do not believe that generators are ever the primary cause of electrostatic troubles outside of the station. Good line and cable construction, effective lightning protection, the grounded neutral, and automatic relays tend to lessen the primary causes and curtail the disastrous effects of insulation breakdowns. High-power short-circuits require a time-element to produce disastrous results. If the excitation of the alternator can be cut down proportionately to the speed with which the load approaches short-circuit conditions, and also if this action can be accelerated so that a short-circuit will develop in less than a second, we have accomplished just what Mr. Waters claims for the non-synchronous generator. This is accomplished at the Pennsylvania power station by using an induction motor-generator for excitation, and a Tirrill regulator for holding up the voltage. The characteristics of a combination including an induction-motor-driven exciter with series and shunt field, the latter controlled by the main generator voltage, are suitable for maintaining operation under all conditions except those due to short-circuits. When a short-circuit occurs, the field of the exciter is "boosted" in an endeavor to hold up the generator voltage. This accelerates the approach to short-circuit conditions, and produces a practically instantaneous interruption, by automatically "killing" the excitation. This scheme was adopted upon the assumption that the interruptions in railway service were of less moment than the troubles consequent upon an endeavor to hold up the excitation at all hazards. In this particular case, therefore. the non-synchronous generator does not possess an advantage.

10. *Overload capacity.* The overload capacity of five times normal full load is an advantage if we have: first, the turbine to carry this load; and, secondly, sufficient steam to drive the turbine at the higher load and higher water rate. The average synchronous turbo-generator is good for two-and-one-half to three times full load on swings. I cannot recall in my experience any case where the overload capacity of the non-synchronous

generator would have any advantage over synchronous turbo-generators.

11. *Strong balancing and damping action.* These characteristics are supposedly of benefit in parallel operation, and probably are intended for comparison with slow-speed synchronous generators. The parallel operation of synchronous turbo-alternators is sufficiently satisfactory for any advantages to be of little value. The damping action has a tendency to correct any irregularities of the sine waves of the system, thus preventing harmonics. This may or may not be an important advantage; it requires more thought for a decided opinion than I have been able to give to the subject.

12. *Adaptability to parallel operation, particularly when the prime movers are gas engines.* This is answered, so far as synchronous turbo-alternators are concerned, in the previous statement. I have never had occasion to become sufficiently familiar with gas-engine practice to venture an opinion. I hope to hear this point discussed by others.

13. *When used with synchronous converters is superior to engine-driven, direct-current generators.* This point appears to be well taken, and I believe here is the field of the non-synchronous generator. Turbine-driven direct-current generators have not proved very satisfactory, and it is doubtful if they will ever be used to any great extent. The slow-speed engine-driven sets are efficient for one point of load, and very uneconomical when the load varies through wide ranges. The non-synchronous generator and synchronous converter combination may show sufficient economy to displace engine-driven generators in some stations, and should generally be able to merit adoption when additional power is required.

The disadvantages are:

1. *Inability to furnish a lagging power-factor.* This involves the use of compensating arrangements to neutralize leading currents.

2. *Requires a lagging current for magnetization.* This involves a power-factor less than unity and may generally be considered an unimportant objection.

3. *Requires that the magnetization current be under excellent control.* This is important where there are large overhead or underground distributing systems, as the electrostatic change due to the grounding of one leg will have an immediate effect upon the power-factor.

In systems having long aerial transmission lines and rather high induction the synchronous converter would have to be considerably over-excited to produce the necessary lagging current for the generator. If an overload should occur, the supply of lagging current would increase; if the overload caused several circuits to open automatically, the induction would instantly fall to a very low value, and unless the power-factor control of the exciting converter were not equally active there would be a rise in potential in the system. This rise would be aggravated if the exciting converter were situated at a substation.

In systems having large capacity in underground cables, either artificial induction would have to be provided or the generators and turbines must be very large. It is shown that the capacity current of the Interborough system would excite a 10,000-kw., 11,000-volt, 25-cycle generator. This would not be a disadvantage if there were not periods of time when the load would be less than half this rate.

I should be pleased to learn if Mr. Waters has considered the possibilities of single-phase non-synchronous generators, particularly the 15-cycle type.

The matter of installation costs has not been gone into very deeply and would be one of the first things to be considered by a designing engineer.

Mr. Stone describes a vertical synchronous converter which appears to possess a number of improvements over the older types. The use of a step-bearing requiring oil pressure lubrication has been so thoroughly proved practical that we cannot consider it an objection. It appears to me that the greatest objection to this type of machine is the possibility of mechanical damage due to the magnetic pull of heavy armature short-circuits.

The arrangements for changing the pole relations for voltage adjustment are valuable in railway operation where the load conditions change from time to time. The device would not be so important if the generators were non-synchronous.

Mr. Woodbridge dwells at length on the following matters—six- versus three-phase converters, high versus low armature reaction, and compounding.

If the efficiency and maintenance of the two types of converters are equal, or nearly so, the operating engineer cares but little about the fine points of phase relations.

The value of compounding is generally a hard matter to decide. Mr. Woodbridge has discussed this point with commendable clearness.

High armature reaction imparts to a synchronous converter some of the characteristics of the induction motor, and enables alternating-current starting; it also means lower synchronizing power. By lower synchronizing power I mean the inability to stay in synchronism with the generator when the power-factor is low. My experience with a system where both types of converters were used, indicates that an overload condition giving a drop in voltage and sufficiently low power-factor to cause the high armature reaction converters to drop out, would have no effect on the low armature reaction converters.

I was opposed to the induction motor type of starting converters until experience proved that it was sufficient for the service requirements. I have seen a small motor start a 1,500-kw converter four times in succession without trouble, and on the Long Island Railroad system, where the interruptions have at times been rather numerous owing to lightning, there has been absolutely no trouble with the starting motors.

Chas. P. Steinmetz: I fully agree with Mr. Woodbridge. I should, however, consider it still better engineering not to choose the unity power-factor point at half load, but at a still higher load, somewhere between three-quarters and full load. This gives a condition of operation where the wattless lagging current at no load and light load is somewhat greater, though still moderate, but the power-factor at full load and overload is better, and the overload capacity, stability, and reliability greater.

When this type of "split-pole" converter was first brought to my attention, I was not very favorably impressed with it; I rather feared, as result of a preliminary investigation, that this machine would give considerable wave-shape distortions, a poor power-factor and poor commutation, for the same reasons that have been clearly explained by Mr. Lincoln. When the machine was built and tested I was surprised that the bad wave-shape distortion did not materialize. The machine gave a good sine wave, the power-factor was high, and the commutation good. When machine after machine, of various sizes, passed through test into commercial service without showing any wave-shape distortion, or poor power-factor, or poor commutation, I was consoled by hearing that another engineer well known to you all, had also come to the same mistaken unfavorable conclusion regarding this type of converter, and from the same point of view. There is, however, no reason why the machine should not give a perfect sine wave, unity power-factor, and good commutation.

The conclusion from this incident is, that even now it is occasionally desirable to check theoretical reasoning by experimental test, because these two do not always agree; not that the theoretical reasoning is wrong, but because in the premises on which the theoretical reasoning is based, some elements which are essential may not have been given the proper weight.

I am very much interested in the induction generator, for I once believed I had invented it. That was about fifteen years ago; but I found out afterward that long before me, the prominent French engineer, M. Leblanc, had gone over the field thoroughly, experimentally as well as mathematically, and that I was somewhat too late. Considerable work was done afterward by other investigators in developing this type of generator—Bradley, Lamme, and especially by Stanley and Kelly. It has found entrance into technical literature, and performance curves of synchronous motors or converters operated from induction generators are to be found in text-books. In the Standardization Rules of the Institute, this machine and the methods of testing it have been described for ten years. There it is given under its usual name of induction generator. I am sorry to see that Mr. Waters chooses to introduce a new name for this well-known type of apparatus, as this practice only leads to confusion. In the Standardization Rules, the name " induction generator " is analogous to the name " induction motor ", and implies the excitation of the machine by induction; the name non-synchronous machine is rather a misnomer, since the non-synchronous machine is the alternating-current commutator motor, in which the speed has no relation to the frequency. This non-synchronous machine is dependent on the speed for its frequency; it is " near synchronous ", but should no more be called a non-synchronous machine, than a direct-current shunt motor should be called an " inconstant speed motor ", because the speed varies slightly with the load. I do not think it is a good idea either, to name an apparatus by what it is *not*.

This induction generator has not been used to any great extent in engineering practice, due to the limitations imposed by its character. It cannot operate on every kind of load, but requires a load of leading current, or consumes wattless lagging current. The proper field for its use is to supply power to synchronous apparatus, motors as well as converters. I do not need to go into this, because it has been so well discussed by Mr. Waters.

The excitation of the induction generator is supplied by the wattless current delivered by the synchronous apparatus, or by the cables. There are a great many advantages in the use of an induction generator, as discussed in the paper: its greater stability and lesser liability to all those ailments incident to the flow of practically unlimited power in the system, as may occur in the synchronous machine; but it must be realized that naturally there is another side to it. If the disadvantages due to the possibility of unlimited power are eliminated, there are also eliminated the advantages resulting from an unlimited power supply. That means the voltage regulation of a system with induction generators cannot be so good as that of a synchronous generator system; for in the last analysis the voltage regulation of a system depends on the excitation of the system, on the direct-current supply to the fields. In the synchronous-generator-synchronous-converter system there are, as fixed voltage points, the generators as well as the receiving converters. In the induction-generator system the only fixed voltage points are the receiving converters, not the generators, and this cuts down the power of voltage regulation to one-half. The trouble of excessive currents is eliminated, but the regulation is somewhat impaired. The use of the wattless charging current of underground cables to help out excitation is an assistance, but at the same time is connected with some serious dangers, because the cables are of constant capacity, and the current taken by them, therefore, is proportional to the voltage. In an induction generator the voltage is proportional to the wattless current received by it, so the machine is liable to build up on its own voltage, just as a direct-current shunt generator below saturation is liable to do. That is, the more excitation is derived from constant capacity, as in underground cables, and the less from synchronous machines, the more fluctuating and unsatisfactory is the voltage regulation of the system. In developing such a system of induction generator operation, there are undoubtedly a number of features and problems which will have to be solved, and which are not always anticipated. For instance, since the voltage depends on the amount of leading current fed into the system, any connecting or disconnecting of synchronous or induction generators, changes the voltage of the system by eliminating the need for so much exciting current, and any converter change, disconnection or connection, changes the voltage of the system. The voltage regulation of the system is taken away from the generating station and located in the converter sub-stations. The latter may be, as pointed out by Mr. Waters, a rather serious feature with a generating station designed for complete voltage control. Such difficulties would be reduced where induction generators are used together with synchronous generators in the generating station.

As to the use of induction generators in a general system of distribution for light and power, probably at 60 cycles, the case stands very much less favorably for the induction generator, due to the large size of its synchronous exciters, for, after all, the synchronous machine must be considered as the exciter of the induction generator, and not the small commutating machine which excites the synchronous machine. Therefore, if the excitation is not given by the load, in using synchronous receiving apparatus, the exciter is rather a big synchronous machine. With high-speed generators of low frequency the exciting current required may be as low as 10 per cent. At lower speeds and higher frequencies it is probably nearer 30 per cent. Even if it is only 10 per cent., in addition thereto the synchronous exciting machine must also supply all the lagging currents consumed by the system of distribution. A system of distribution for light and power at 90 per cent. power-factor, is possibly above the average. 90 per cent. power factor means 44 per cent. inductance factor, and adding thereto 10 per cent. magnetizing current of the induction generator brings the total amount of exciting current up to 54 per cent.; that is, a synchronous machine used as an exciter of the induction generator would be more than half the size of it, rather a large size. This precludes the use of induction machines of the type as described by Mr. Waters for most cases of operating a general system.

In this direction, a very great advance has been made by Messrs. Stanley and Kelly, and was reported and fully discussed in a paper presented by them a few years ago before the Institute. The induction generator has two circuits, the high-frequency circuit supplying power to the outside, and the low-frequency circuit. Instead of applying the magnetizing current to the stator, as the high-frequency member, Stanley applies the magnetizing current to the low-frequency member of the induction generator; and as the volt-amperes required for excitation of the alternating field are proportional to the frequency, by exciting the induction generator, not from the high-frequency stator, but from the low-frequency rotor, Stanley cuts down the exciting volt-amperes from 50 per cent. of the generator capacity to one or two per cent. This requires, then, an alternating-current low-frequency exciter operating at one or two per cent. of the induction generator capacity, a practical machine. In this way, the great objection to the induction generator, of requiring a large synchronous exciter, can be eliminated. The exciter may be a synchronous machine or an alternating current-commutating machine—at such a low frequency as one cycle, or a fraction of a cycle per second, a commutating machine operates very satisfactorily with an alternating field—or an effective capacity as the electrolytic cell, may be used to supply the leading exciting current to the rotor. The interesting self-compounding features of this Stanley induction generator are discussed in that paper.* This method of excitation naturally also imposes certain limitations; it means that the rotor is less simple because currents have to be fed into it from outside sources; it means probably collector rings or direct connection to a generator of low frequency.

There are some very interesting features of the induction generator which have not been mentioned in Mr. Waters' paper; one is that the induction generator does not require a synchronous machine for excitation, but can also be excited by capacity, as the capacity of a cable or an electrolytic cell. The induction generator, then, assumes a characteristic very closely similar to that of the direct-current shunt generator; that is, as the amperes consumed by a constant capacity are proportional to the voltage, and the voltage of the induction generator is proportional to the amperes excitation—if the capacity is too low, the induction generator does not excite, does not energize; if the capacity is sufficiently high, it energizes and the voltage builds up until it passes beyond the bend of the saturation curve and there the machine becomes stable and is a self-exciting alternating-current generator having the same characteristics as the direct current-shunt generator. It shows indeed a very close analogy thereto. The farther beyond the bend of the saturation curve, the more stable the machine becomes. On heavy overloads, especially of lagging current, the induction generator is always liable to lose its excitation; that is, to lose its voltage, just like a direct-current shunt machine, while the synchronous machine will hold up. This may be an advantage, or it may be a disadvantage.

There is, however, one field to which I believe the induction

* Alternating Current Machinery—Induction Alternators, TRANSACTIONS, A. I. E. E., 1905, Vol. XXIV, p. 851.

generator is preeminently suited, and that is where water powers are operated in parallel with steam power. In those numerous cases where a water power of limited size is available, and the balance of power beyond that given by the water wheels is supplied by a steam plant, the problem is to take all the load possible from the water power and supply the only deficiency by the steam power. In this case a synchronous machine would be used on the steam engine operating at constant speed, while the induction generator connected to the water wheel would operate without governor on the water wheel—except an excess-speed cut-out. In that case the induction generator speeds up above synchronism until it consumes all the power given by the water, little or much, depending on the conditions. All the power which the water can give is thus supplied to the system; the steam engine supplies the rest. This is a case of parallel operation where a division of load is not desired, but it is desired to take all the available power from one plant, and the rest from the other. To this case the induction generator is eminently suited.

There is still another field, far broader than anything touched so far, in which the induction generator only can be used and the synchronous generator is out of competition—in the use of an aggregation of small water powers.

There is an enormous amount of power now going to waste; scattered in small creeks and rivers and brooks. There will come a time when the large water powers are developed and used and the problem of gathering the power of all these small streams and creeks will have to be approached and mastered. Only the induction generator can solve the problem. Consider, for instance, one of the numerous little creeks of the New England states, with a limited amount of water, a fall probably of from 200 to 2000 ft. within 5 to 20 miles. Hydraulic development on present lines there would be out of the question; to bank up the creeks, to gather considerable head, and to carry the whole pressure in a pipe-line several miles long would be so expensive as to be impracticable. But there would be a considerable amount of power, if, instead of one of these creeks, there could be combined the power of dozens or hundreds of them. While it would not be economical to develop a single small power, yet where numerous small water powers can be combined it is a practical problem which will have to be solved. The way to solve it, I think, is by building small stone dams across the creeks, just high enough to get a supply head of a few feet, to feed into a pipe of a few hundred feet long—ordinary water pipe—and thereby gather a head of some 50 or 100 ft. The water discharges from the pipe against some simple form of hydraulic turbine, and the induction generator is directly connected mechanically to the turbine, and directly connected electrically to the low-tension side of a step-up transformer. The high-tension side of the step-up transformer connects to a transmission line leading along the creek. A number of such small generating stations, which would be simple and cost but little, could be strung along the creek or river, all feeding into the same collecting line. A number of such collecting lines from different creeks could join together in a center of collection. In this manner the total power of all of these streams and creeks could be carried into one central collecting station. The power thus generated and gathered could be distributed to the consumers.

In this field the induction generator is the only feasible type of apparatus. In such a system each station must require no attention whatever beyond a systematic inspection, and must be of the simplest possible character. This excludes synchronous machines with their exciters, switchboards, turbine governors, etc. With a direct-connected low-voltage induction generator, the turbine would run without governor, absorbing whatever power is available, and speeding up until the induction generator slips above synchronism sufficiently to transfer the power to the collecting line as electric current, or, if the line should be idle, broken or so, speeding up to the free running speed, 60 to 70 per cent. above normal. Even the lubrication of the bearings may be by water. The only safety devices would be fuses to cut off the station in case of an accident, which is rather improbable with low-voltage induction machines.

Comfort A. Adams: Although Mr. Waters' enthusiasm has induced a somewhat optimistic point of view, there are certainly many instances where the induction generator is decidedly superior to the synchronous generator. One argument made in this connection by Mr. Steinmetz may leave a somewhat erroneous impression. He cited the case of a lagging load with a 90 per cent. power-factor, where the synchronous exciter would be obliged to supply not only the 10 per cent. exciting current for the induction generator, but also the 43.6 per cent. lagging quadrature current of the load, making necessary an exciter capacity of 53.6 per cent. This sounds like a very bad case for the induction generator; but Mr. Steinmetz failed to state that in the case of this same 90 per cent. power-factor load supplied by a synchronous alternator, the latter would be obliged to supply the 43.6 per cent. quadrature current, and that therefore the combined capacity of the induction generator and its synchronous exciter would exceed that of the synchronous alternator by only 10 per cent., the amount of the exciting current of the induction generator.

Concerning that very interesting and puzzling machine, the split-pole converter, I cannot but believe that when we know *all* the facts as to its construction and operation, the apparent gap between the results of theoretical analysis and those of experiment will be reduced to inconsiderable dimensions. Two or three factors which play some part in this explanation have already presented themselves, and will be expanded at a later date, when more information regarding the details of the machine in question is at hand.

One suggestion, however, may be made now; namely, that with a delta connection for the three-phase, or a double delta for the six-phase converter, the third and ninth harmonics disappear, which would considerably reduce the sine deviations found by Mr. Lincoln for the diametral connection.

J. R. Bibbins: Aside from the purely scientific interest surrounding the theory and application of the non-synchronous generator, Mr. Waters' paper is most interesting, embodying as it does the design and experience of a concrete case, which many of us have followed with interest since its installation several years ago. Personally, I am particularly interested in this type of generator from the standpoint of prime-mover design, and Mr. Waters has presented two developments which involved a number of important points. His treatment of the subject makes it reasonably clear that the flexible speed-characteristics of the non-synchronous generator, renders it particularly well adapted to direct connection to prime movers in which cyclic or angular variation of speed is permissible within unusually wide ranges, as in present synchronous generator practice. This feature would, of course, have no bearing upon turbine practice, in which angular variation is absent, but might be taken advantage of in utilizing simple forms of reciprocating engines, such as single-cyclinder steam or gas engines.

But in his remarks concerning the modern double-acting gas engine, I believe Mr. Waters' enthusiasm has led him to give an erroneous impression in regard to the possibilities of this type. To obtain the same degree of satisfaction, there does not exist such an ernomous difference between gas and steam practice, either in the matter of flywheels or dampers, as his remarks would indicate. Even if so, the matter of fly-wheels would not seem to be such a serious one, inasmuch as the cost-factor of the iron that enters into fly-wheel construction is barely 30 per cent. of the cost of the finished product in the other parts of the engine. And inasmuch as windage loss is largely occasioned by fly-wheel arms, the increase in loss due to an increased weight of rim would scarcely be noticeable, nor the increase in bearing friction due to the increased weight of rim. It seems probable, therefore, that the 3 to 5 per cent. loss due to friction and damper work ascribed to the gas-engine-driven unit would not apply to a properly designed machine of the tandem or twin-tandem type.

Philip Torchio: Three years ago a New York lighting company was short of 60-cycle generating capacity, and contracted with a manufacturer for the purchase of a 2000-h.p. non-synchronous generator to be coupled to a 25-cycle motor, for use as a frequency-changer. The reason of this departure was on account of the manufacturer having the frames of the machines, and the company requiring quick delivery.

On account, however, of the impracticability of making the necessary changes in the short space of time available, the proposition was dropped and I am therefore unable to give to-night the actual experience with a non-synchronous generator in connection with a large system.

I endorse what has been said regarding the use of non-synchronous machines in large power stations where the field does not seem to be very promising. I want to call special attention to the figures given by Mr. Waters, where he states that the whole system of 200 miles of high-tension feeders of the New York Edison Company, capable of supplying 150,000 kw., would only supply magnetizing current for a 2000-kw. generator, or less than two per cent. of the station generating capacity.

Regarding the point Mr. Waters makes about the non-synchronous generator reducing surges, I would qualify its practical importance. On an underground system, as of course in any system there are surges whenever the load suddenly changes, while the circuit is closed these surges are not so large as in the case when the circuit is abruptly opened. If the circuit is opened at the instant large currents are flowing, then all the energy stored in the inductance of the circuit oscillates at the period of the circuit between electrostatic energy and electromagnetic energy, and one can figure out that if there were no damping effects due to the resistance of the copper, disastrous voltages might result. As a matter of fact we do not get them, because the oil circuit-breakers open the current at zero or near zero value. I do not see how the conditions would be bettered with induction generators.

Mr. Stone says that to prevent hunting the squirrel-cage coil in the pole tips is the proper thing to use, in which I agree. However, from experience with large systems as operated in New York, it has been found that the ordinary copper grid on the pole pieces has given exactly the same results as the short-circuited coils buried in the iron of the pole tips.

I think it might be well to put on record the *whole year* efficiency of a large system operating over 100,000 kw. of synchronous converters. Including all the losses from the generating station to the low-tension bus-bars of the sub-stations; namely, the losses in transmission lines, static transformers, induction regulators, converters, and all connections—the whole-year efficiency ranges between 90 and 91 per cent. That efficiency has been obtained for several years.

J. B. Taylor: Mr. Clark has well expressed my ideas of Mr. Waters' paper on the induction generator. I concede to this generator two advantages: better mechanical construction, and less destructive effects on short-circuits. The other points mentioned seem to be rather in the nature of disadvantages than advantages. The matter of excitation has been already well taken up, and a point I want to dwell on is the fact that the claimed simplicity in the generating station has been obtained entirely at the expense of the sub-station. The sub-station must be ready to start up converters and excite the generators whenever necessary. Just how they would tell when it is necessary, I do not know. It would probably be a matter of establishing telephone communication, and getting the converters under way from storage-batteries, which, if available, have been installed in order to carry the load in times of emergency. These would, therefore, not be in the best condition for carrying the extra load of inverted converters. Then the generating station would have to determine, and bring the generators to, the speed of the converter. If the converters are thrown on to a lagging load, everything may speed up to a dangerous point, since lagging load, as we all know, weakens the field. In other words, there would be a great range between the low speed when connected to cables with leading currents, and high speed when connected to generators with lagging currents.

As more converters are brought to the speed of the system and connected in, more generators can also be connected in. After a time, depending on intercommunication between stations with attendant delays and misunderstandings, all will be in service.

Another point I wish to dwell on is the reference made in the papers and discussion to the disastrous effects of harmonics and departure from sine waves on operating systems. This is an old story, but at the present time I do not know of any case where the wave-form has been shown to be responsible for any case of resonance and where it has been necessary to take steps to change the wave shape or in any way to modify the constants of the system to eliminate this resonance.

There is a story that an old fiddler was playing a violin near a bridge in course of erection. Resenting some personal remarks made about his performance, he started to play, and, finding the note that resonated with some natural period of the bridge, he finally had the bridge shaking so that it would have fallen down if due apology had not been made to him. None of us ever saw such a performance, and never will, for the reason that a violin could not carry sufficient energy to supply the losses incidental to vibration of a bridge structure. Similarly, harmonics on an alternating-current system do not cause destructive resonance, mainly because there is insufficient supply of energy at the harmonic frequency to supply the accompanying losses in copper and iron. If any one knows of a case where an irregularity in the wave-shape of a system, call it the third harmonic or any other harmonic, something due to the wave shape, of the generator, has caused trouble by resonance, I shall be glad to hear of it.

W. L. Waters: Mr. Stone apparently advocates the use of vertical shaft converters, for a number of reasons, but taking the data on these machines as given by him, the reasons do not appear to be sufficiently important for engineers to change their standard type. Taking the 2000-kw., 250-volt converter, which he describes, the horizontal type converter operates at 115 rev. per min., while the vertical operates at 166 rev. per min. The weight given for the horizontal shaft machine is 186,000 lb. The speed has been increased about 45 per cent., while the weight has decreased about 30 per cent. Then again this increase in speed has only resulted in a reduction of about 15 per cent. in the floor space. I would point out that these reductions are obtained just as easily in a more recently designed horizontal-shaft machine. This vertical type of machine introduces new uncertainties into the design and operation, this uncertainty being specially the case in regard to the vertical footstep bearing. Roller and ball bearings have been tried for a number of years, but have never been successful for heavy work; and the alternative of an oil pressure bearing depends on maintaining a high-pressure oil circulation. The standard horizontal shaft machine with oil-ring bearings has been in service now for a number of years and there is no doubt about its operation. By the adoption of the vertical type of converter, we are merely introducing extra complication and risks and are gaining practically nothing.

Referring to Mr. Stone's remark on voltage regulation, he describes the method which makes use of a rotating armature alternating-current booster mounted on the shaft between the main armature and the collector rings, and permanently connected in series with the converter collector ring leads. In reference to this, Mr. Stone says that this development " took place abroad," and further that " a few machines of this type have been built by one of the large manufacturing companies in this country." In reference to these statements, I would like to point out that this method of voltage regulation was developed and patented by Mr. C. F. Scott fifteen years ago. and that at the present time there are 10,000 kw. of this type of converter running in New York City alone. The only reason why this method of regulation had not been adopted earlier, is that until recently it was considered preferable by operating engineers to insert induction regulators in the feeder circuits rather than to vary the converter voltage itself. The objections against this type of machine which are put forward by Mr. Stone are: the extra weight on the shaft, decreased ventilation, lesser accessibility, and increased liability to break down. The extra weight on the shaft is about 15 per cent. and can easily be taken care of. The decreased ventilation is evidently unimportant, as the temperature rise on most of these machines as actually built is about 20 degrees on full load. The question of accessibility is unimportant except in the case of repairs o· cleaning out the machine.

In regard to repairs, Mr. Stone states that " any serious trouble with this smaller machine results in the dismantling of the main synchronous converter in order to repair the small booster". If Mr. Stone expects ".serious trouble" with this booster wound for 15 volts, it would be interesting to know what he expects to happen to the converter itself which is wound for twenty times this voltage. He proposes as a preferable arrangement that an overhung revolving field booster be supplied. This would mean extra collector rings and extra complication in regard to cables and increased floor space, and in addition we would have a revolving field wound for 125 and 250 volts instead of a revolving armature wound for 15 volts. Referring again to the question of floor space, I would point out that as the distance between bearing centers in a horizontal shaft converter is to a great extent decided by questions of mechanical stability, there is practically always space enough between the armature and collector rings to insert a revolving armature booster. In any case, the extra length along the shaft necessary to take care of such a booster would not exceed 10 in. or 12 in., while the extra length required for a revolving field booster would probably be 2 ft. to 2 ft. 6 in.

The question of six-phase versus three-phase is entirely a manufacturing rather than an operating engineer's question. It is to be decided by which is the cheaper machine in any individual case. The great advantage of a six-phase converter is, as Mr. Woodbridge has pointed out, that it saves armature copper. There has been a tendency on the part of some manufacturers to pay more attention to theoretical considerations than to operating conditions when deciding the amount of copper to be put on the armature of the converter. It was often decided because the total armature copper loss in the six-phase converter was only one-quarter of that of the corresponding direct-current generator, that it was advisable to reduce considerably the section of copper in order to reduce the cost. This method of designing was finally stopped by the operating engineers themselves, who refused to take converters with such small sections of copper, having found by experience that theoretical considerations were not always verified in practice. At the present time it has been shown that the only way to design converters for heavy service is to allow ample copper on the armature, and that it is advisable to design the machine irrespective of whether it is to operate three-phase or six-phase. Further, the question of using the extra three collector rings as balancing rings for the armature is again a manufacturer's question. If we want more balancing rings on a converter, they can be put on without regard to the collector rings. And in a large number of cases the extra three collector rings and cables are merely an unnecessary complication, this being especially the case in 60-cycle converters where the section of armature copper is decided by mechanical reasonss and where the current density is very low. Mr. Woodbridge', statement, "but in any event a three-phase machine may be safely increased in rating some 40 or 50 per cent. . . . by the addition of three more collector rings" hardly needs criticism, as any engineer who has designed or operated modern converters knows that it is not the heating of the armature but the sparking or flashing at the commutator that decides the rating of a converter, and these are not influenced by change from three-phase to six-phase.

Taking the question of starting converters, the method advocated by Mr. Woodbridge which is direct application of alternating current to the armature windings through the collector rings, can only be applied satisfactorily on machines with either no dampers on the pole faces or else with only very light dampers. The reason for this being that with heavy dampers there is flashing at the commutator when starting. If we are willing to endure hunting of the converter on light loads or on certain conditions of the circuit, then we can run with light dampers and start up in this way. In any case, however, this method is not a good one from the operating engineer's point of view. Taking Mr. Woodbridge's own figures, it takes from two-thirds to three-fourths the normal rated kilovolt-amperes to start the converter in this way. The power-factor of this current will be about 20 per cent. If we have an induction motor for starting the converter, this motor will take about 30 per cent. of the full rated kilovolt-amperes of the converter when starting, and this current will have a power-factor of about 80 per cent. Thus with a starting motor we take wattless kilovolt-amperes equal to 18 per cent. of the normal rated kilovolt-amperes of the converter, while starting directly from the alternating-current side of the converter armature we take wattless kilovolt-amperes equal to 70 per cent. of the normal kilovolt-amperes; that is, starting as advocated by Mr. Woodbridge takes four times the wattless kilovolt-amperes which would be required with a starting motor. The watt kilovolt-amperes taken from the system is unimportant in either case, because it is always the wattless amperes which upset the regulation of a system. These figures show us at once, why, if a large converter system is shut down, it takes so long to get the system started again when we try to start the converters from the alternating-current side. Mr. Woodbridge states that the converters would not start up simultaneously so that the power station could carry the wattless load satisfactorily. We might add to this that in certain cases where they have tried to start up simultaneously the power station has been unable to keep the voltage high enough to start the converters.

The two most reliable methods of starting converters are:

1. An induction motor wound for slightly higher synchronous speed than the converter and with a high resistance secondary. The induction motor is thrown directly on the full alternating

voltage, and as the machines come up to speed the main alternating-current switches are closed through a resistance. This resistance limits the synchronizing current and enables the machines to get in step quietly. The resistance is then short-circuited and the induction-motor circuit is opened.

2. A small induction motor-generator starting set installed in the sub-station, this being used to start the converters from the direct-current side.

These two methods, one for starting from the alternating-current side and the other starting from the direct-current side, are undoubtedly the most reliable methods of starting a converter. The method advocated by Mr. Woodbridge requires extra complication of cables and switches, and extra taps on the transformers. It will, however, usually work out that Mr. Woodbridge's method is cheaper; and it is a question for the operating engineer to decide as to whether he prefers cheapness in first cost or reliability of operation.

I think that it is pretty evident that there must be *some* distortion of wave-form when the voltage ratio of alternating current to direct current in a converter is varied by the split-pole method; the only question is to what degree the wave-form is distorted. Mr. Steinmetz says that a sine wave is obtained under all conditions of voltage ratio. I think, however, he must be speaking in a general way, because it is evident that a pure sine wave can only be obtained when the distribution of magnetism also follows a sine wave which cannot possibly be the case under all conditions of voltage ratio in a split-pole conververter. I wouid point out that the power-factor as obtained on a power-factor meter would give no indication of such distortion, as a power-factor meter does not take into account the higher harmonics. Possibly Mr. Steinmetz forms his opinion from oscillograph records taken from such converters. I would like to point out that the average commercial oscillograph is, comparatively speaking, an incorrect instrument, and that its record depends to a great extent on the various adjustments of the instrument. So that unless extreme precautions are taken by an experienced and skilful operator, I would rather take the calculated wave-forms than those obtained by an oscillograph. A very simple way to show that distortion is present is to measure the power-factor of the converter running light from the direct-current side and under different conditions of voltage ratio, such power-factor being measured by taking readings of volts, amperes, and watts. I think such a power-factor reading will show at once that very considerable distortion has taken place.

Mr. Clark's criticisms are conservative and well taken, and are generally such as we would expect from experienced operating engineers when such a comparatively new proposition is put before them. He refers to the size of the air-gap on this type of machine. The clearance between the rotating and stationary part varies from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. He refers to the use of non-synchronous generators for 15-cycle single-phase traction power generation. The non-synchronous generator would be an especially good machine for such work, so long as the power-factor was not too low. Usually the power-factor in such a station can be kept about 85 per cent., and in such a case the non-synchronous generator would compare very well with a synchronous machine. It would behave considerably better than a synchronous generator on short-circuits, and would be less liable to damage, and for such a low frequency could probably be designed to be quite a little cheaper. The wattless current would, of course, in this case have to be supplied by high-speed synchronous motors running light in the power station. Mr. Steinmetz objects to the size of the synchronous motor necessary to employ in order to supply the wattless current in a system of non-synchronous generators. I would point out that each case must be considered in itself, and in the case of the gas-engine-driven station described there are 3500 kw. non-synchronous generators each requiring a 4500-kw. synchronous motor, and yet this station proves to be a commercial proposition. The size of the synchronous motor is immaterial so long as the first cost, maintenance and efficiency do not prove unfavorable.

Referring to the other non-synchronous motors mentioned by Mr. Steinmetz; namely, those of Stanley and Heyland, these were not mentioned in the paper as they were hardly considered commercial machines. The necessity for a coil winding and collector rings, on the rotating part, takes away practically all the advantage of simplicity in construction which the non-synchronous generator possesses. Such machines would hardly be considered for American power station work.

J. E. Woodbridge: Mr. Clark made a statement to the effect that as long as converters operate satisfactorily, a difference of a few per cent. more or less in power-factor is immaterial. This is true if the machines do operate satisfactorily, but a few per cent. difference in power-factor occasionally makes the operation quite unsatisfactory. A case has recently been reported where a converter smoked badly on a guaranteed overload. When this converter was run at unity power-factor it carried the same overload for a greater length of time with a temperature rise of only 30° cent. As I stated in my paper, railway converters work, as a rule, under such low load-factors, and are designed for such heavy overloads, that a few per cent. more or less in power-factor gives no trouble, but when converters are worked near their guaranteed loads the power-factor is relatively important.

Mr. Clark also referred to the low "synchronizing power" of converters with a high ratio of armature to field ampere-turns as compared with those of a lower ratio, and spoke of machines with the former characteristics dropping out of step on loads which the other machines would carry. My experience has been limited to railway work where machines are normally protected by circuit-breakers, and I have never heard of a case of a machine being pulled out of step by load. If the circuit-breakers are blocked, the alternating-current automatic protection, whatever it may be, unless also blocked, will operate on sufficient overload, and it is impossible to state whether this automatic protection is due to the load or to falling out of step on the part of the converters. I believe no case of this kind can be substantiated, with the exception of loads so great as to drop the voltage to zero, that is, short-circuits.

Mr. Waters gave a figure that I wish to dispute, namely, the power-factor of the starting currents of converters. With converters with narrow air-gaps, high armature reaction, low field densities, and with short-circuiting pole-face windings, I am positive that the power-factor of the starting currents is much higher than the 20 per cent, which he gave, although I have not made any direct tests on this point. For one reason, 20 per cent. would not, as a rule, give sufficient torque to start the converter in all cases, allowing for no losses or any kind whatever. A test which I do remember, showed a starting current of roughly 1500 amperes in the secondary connections which went down to 300 amperes magnetizing current when the machine reached full speed and before the field was excited. This indicates a power-factor at the converter approaching 98 per cent., but the magnetizing component was undoubtedly somewhat greater, due to the influence of the currents in the pole-face windings at lower speeds. I think that the power-factor can safely be stated to be somewhere between 70 and 80 per cent., which compares favorably with the power-factors of starting induction motors.

The input of a starting induction motor is not so greatly different from that of a self-starting converter with the characteristics described in the paper; for example, a 1500-kw. converter which I was watching this afternoon required 400-kw. for starting by means of an induction motor.

With regard to the recommendation of Dr. Steinmetz, that transformer and converter voltages should be so proportioned that compound converters would reach unity power-factor at about full load, such a radical departure from existing practice was more than I dared to suggest. Experience indicates that when transformers give such a high secondary voltage as to meet this condition, thereby giving an abnormally high direct voltage at no-load unity power-factor, either the operators run at that voltage and are glad to get it, or run at that voltage and grumble at it, either of which condition is rather unsatisfactory. With transformer ratios designed to give unity power-factor at full load, with a representative amount of resistance and reactance in circuit, unity power-factor at no load gives about 10 per cent. over voltage; that is to say, a 600-volt converter would run at no-load unity power-factor at 650 to 660 volts. To force it down to rated voltage at no load would require an alternating-current lagging input at no load amounting to 50 to 80 per cent. of the rated full-load current of the converter, according to the strength of the series field. I believe few operators would properly handle an equipment of this kind. They would simply run 5 or 10 per cent. above voltage.

C. W. Stone: If all the statements just made by Mr. Lincoln and apparently supported by Mr. Scott were borne out by the facts as demonstrated by the machines which have actually been built and tested, I should feel that I had made a grave mistake in coming before you and calling to your attention this new type of machine.

It is possible to calculate results which will approximate those that Mr. Lincoln has also reached. However, consideration must be given to other conditions which are apparently overlooked by Mr. Lincoln. The curves shown by Mr. Lincoln are evidently only calculated curves, and not oscillograph curves taken from actual machines. I am sorry that I did not have time to prepare some oscillograph curves which were taken across the collector rings of one of these converters, working through an extreme range in voltage. These curves approximate a sine wave. The higher harmonics mentioned by Mr. Lincoln are not apparent.

Some question was raised about the change in excitation of the main fields in order to maintain minimum current input to the converter. As a matter of fact, the main field excitation, when the load is constant, varies less than 5 per cent. for the extreme ranges in voltage; that is, from the full bucking to the full boosting voltage obtained by exciting the auxiliary field—this on a machine on which was obtained a range in voltage of approximately 175 to 350 volts, the normal being 250 volts.

Some long-continued test-runs were made on machines of various sizes, and it was found that they were all within the heating limits usually specified, and considerably below the guarantees made.

In reference to the cost of the converter built according to the Woodbridge design. In designing a 2000-kw. machine, I had a number of different designs made up to get a comparison of the cost of this type of converter with a converter using an induction regulator; I was unable to find that the converter would cost any more than a converter with an induction regulator built for the same range in direct voltage, the range in voltage being from 200 to 300 volts with normal voltage of 250 volts.

Mr. Lincoln thinks that on account of the wave distortion the converter might have a serious effect on the other apparatus operating on the system, and that in all probability the results obtained in test would not be reproduced when the machines were connected to the operating systems. In order to verify my opinion, I had the machines operated from small machines, from large machines, and in fact from all types of machines, including motor-generators, engine-driven generators, turbine-driven generators, alone and in parallel. With the same excitations the same voltages were obtained, the curves agreeing exactly, irrespective of the type of apparatus or the size of the system on which the converter was operated.

The first machine built for investigating the Woodbridge method of voltage control was made by taking a standard converter, the field spools of which were removed and replaced by some field spools made up of three sections each, on each section of which were placed the two windings in accordance with the Woodbridge scheme. The wisdom of the idea was demonstrated by the operation of this machine. The machine has been in commercial operation considerably for more than a year, and no trouble has been experienced although it has been operated under very adverse conditions.

It is true that in order to obtain the necessary space for the extra field spools, it is necessary to increase somewhat the diameter, and consequently the weight, of the whole machine; but the increase in cost of the converter due to this extra material will just about offset the cost of the induction regulator. I think I am safe in predicting that, after the idea is a little better known, and a little more experience has been had in the manufacture of these machines, there will be still further reductions in the cost.

Referring to the converters using the booster control system, I would say that I have had machines designed both with the revolving armatures and revolving fields. I have compared the cost of these machines with the cost of standard converters using induction regulators and converters made in accordance with the Woodbridge idea, and also converters made in accordance with the Burnham idea. I think that without question the converters built in accordance with the Burnham scheme will be as inexpensive as any.

The question of which type of machine, the revolving armature type of booster or the revolving field type of booster, is the better, I shall not discuss. I think that the revolving field type is the better, but this is a point upon which engineers will necessarily disagree; and in view of the new developments with the Woodbridge or Burnham type of converter, I think this whole question will be eliminated.

Mr. Waters says that roller bearing, used with the vertical type of converter is an old idea, but nobody has been able to make them work satisfactorily. I might say that the type of bearing used in this machine has been in use at Niagara Falls for several years on the Niagara Falls generators, having approximately 30 per cent. more weight and operating at 50 per cent. higher speed. No trouble whatever has been experienced with them.

J. B. Taylor (by letter): The proposed system using induction generators relies largely on converters for excitation, which means that these latter machines must run at power-factors other than unity. These machines as ordinarily designed are not well adapted to run at low power-factor, the increased and localized heating under these low-power factors being ably explained in Mr. Woodbridge's paper.

Too great advantages are claimed for the ease of paralleling induction generators. While exact synchronism and phase relations are not essential for paralleling induction generators, it is essential to have the speed nearly correct. For example, if the slip to give full load is one per cent., a difference in speed of two per cent. when paralleling will immediately subject the machine to twice full load, either as a motor or as a generator, and devices must be provided to indicate the proper speed. Tachometers on the machines cannot, in general, be depended on to a fraction of one per cent.; even with suitable tachometers, these are not readily seen by the switchboard attendant, who is the person most interested in knowing when speed is correct. Devices to show synchronous speed on induction motors have already been devised and placed in service, but these devices cannot be regarded as any simpler than the usual form of synchronism indicator used with synchronous generators. The proposal to connect generators to line, first, through a reactive coil, and then cut out the reactive coil, calls for additional apparatus and switches with additional complication in manipulation; means for adjusting load by pilot motors is already a well worked out device for synchronous machines.

In discussing the split-pole converter, Mr. Lincoln has shown a number of curves of calculated flux distribution and accompanying waves of electromotive force. His general objections to this type of machine on the score of power-factor, wave-shape, and efficiency have been satisfactorily answered by others who have shown that " the best proof of the pudding is in the eating thereof ", since the terrible distortions and losses anticipated have not been found in actual test. Mr. Lincoln's curves, I believe, were all based on a diametrical voltage, and do not hold for the three-phase converter or six-phase converter connected double-delta. The final effect of possible third-harmonic voltages or third-harmonic currents in the system will depend largely on combination of converter and transformer connections.

Mr. Lincoln properly points out the distinction between true power-factor and power-factor as indicated by certain types of instruments which show merely the cosine of the angle of lag rather than ratio of true watts to volt-ampere product. The case commonly referred to in bringing out this point is that of the alternating-current carbon arc, where current and voltage at the arc are in practically the same phase relation, with no angle of lag, and true power-factor is far from unity, on account of the fact that the two wave-shapes are not alike and maximum value of current does not coincide with maximum value of potential. It seems proper to point out here that the principal objection to low power-factor is the demagnetizing action on generators. For low power-factor due to wave-shapes rather than to angular displacement between current and electromotive force, the demagnetizing objection does not hold.

A paper presented at a meeting of the Toronto Section of the American Institute of Electrical Engineers, Toronto Ont., February 20, 1908.

ALTERNATING-CURRENT FEEDER REGULATORS

BY W. S. MOODY

The sensitiveness of the incandescent lamp to changes in voltage, both with reference to candle-power and life of the lamp, demanded very early in the history of electric lighting a close control of the voltage on constant-potential circuits. With the small direct-current generators that were first used this was easily accomplished by the simple field adjustment of the generator, but when the size of the generators increased and several were operated in multiple, several circuits were usually operated from one station bus-bar. With the low voltage used in direct-current distribution, the feeders could not have a negligible drop; therefore an adjustable artificial loss, in the form of a rheostat, had to be inserted in each feeder and adjusted according to the load. We all remember the early direct-current stations in which these rheostats took up almost as much space as the generators, and consumed enough energy to increase materially the cost of operating the plant. In these rheostats is found the first elementary feeder regulator.

In direct-current practice, boosters, storage-batteries, and other devices have long since replaced this wasteful and unsatisfactory method of control. I refer to such historic methods of feeder control only to show how early in the art there arose the necessity of devising some means of maintaining the desired potential at the center of distribution of each feeder.

When incandescent lamps were first operated by alternating current supplied by high-voltage generators and transformers, the need of feeder regulation did not become apparent, because it was several years before generators of more than 100-kw. capacity were developed; and because attempts at multiple operation of such generators were few and generally unsuccessful. For several years then it was the practice to operate only one feeder from each generator, the desired control of potential being obtained by the field of each generator. With the development of large alternating-current generators, and with improvements in their design and the design of the governors of their prime movers that admitted of multiple operation, there developed the same necessity for the control of individual feeders, operated from high-voltage bus-bars, as had years before been experienced in direct-current distributions.

Given an approximately constant potential on the bus-bars, a feeder may be controlled: first, by a variable resistance in circuit with the feeder; secondly, by a variable reactance in series with the feeder; thirdly, by a variable capacity in multiple with the feeder; fourthly, by a transformer whose primary is in multiple with the circuit, and whose secondary is in several sections, any number of which may be thrown in series with the feeder; and fifthly, by a transformer whose primary is in multiple with the feeder, and whose secondary is in series therewith, and which is so built as to admit of shunting the magnetic flux of the primary.

The first two methods; that is, variable resistance and variable reactance, have been used to only a limited extent. The resistance is objectionable because of the loss of energy, and both forms fail in accomplishing the desired result, because they must make the inherent regulation of the feeder worse; that is, the total drop in the feeder is greater than if no such resistance or reactance were in series, and consequently every time there is a change in load, the change in voltage will be greater than if there were no such regulating resistance or reactance in circuit. While therefore with careful attention the desired voltage may, on the average, be more closely obtained by the use of such means of regulation, the variations in voltage will be increased rather than decreased.

Regulation by the use of variable capacity, obtained either from condensers or the leading current of synchronous motors, is possible only on systems having a large inherent reactance. Remarks about this method of control will be deferred until later.

Control by means of a transformer whose secondary is divided into sections, any number of which may, at the will of the operator, be placed in series with the feeder, was one of the first methods successfully worked out for the control of alternating voltage, and has proved one of the most satisfactory. Such a transformer may be readily designed to have as good regulation of its own voltage under varying load as any other transformer, and consequently its introduction into the feeder does not materially affect the inherent regulation of the system. The only engineering problem of consequence involved in the making of this form of regulator, other than the usual transformer problems, lies in the design of a switch that will allow an easy and safe cutting in and out of the various sections of the secondary.

The remaining method; namely, a transformer in which the primary flux may be shunted, ordinarily known as an induction type of regulator, can be built to have substantially as good regulation as an ordinary transformer. It does not have a detrimental effect on the inherent regulation of the system, and is particularly adapted for use on circuits carrying heavy currents, circuits that would require expensive and cumbrous switches if controlled by variation of the turns in the secondary rather than by the flux passing through the secondary.

Resistances have been used to such a limited extent that no special form has been developed, and there is nothing, therefore, to describe, even historically. Various forms of reactances, such as simple solenoids with a moving coil or core, or a moving keeper to a U-shaped core, were used to a considerable extent in some of the earlier alternating stations. As the voltage of a series reactance is so far out of phase with the voltage of a high power-factor circuit, the volt-ampere capacity of the reactance must be very large compared with the results obtained, and the inherent regulation of the system is very much interfered with by their use. Compared with their useful work their size is also greatly increased by the fact that the greatest effect is wanted when the current in the feeder is least, so that there must be turns enough to produce the maximum absorption of voltage when the minimum current is flowing. These objections to reactance control are mentioned because even engineers are sometimes surprised at the size of a reactance necessary to accomplish a given amount of control, and also because it is sometimes thought that the transformer with variable flux; that is, the induction regulator, controls by means of its reactance. This, as I shall show later on, is quite an erroneous idea.

Transformer type of regulator. The transformer part of this type of regulator need not differ in any essential particular from any constant potential transformer of the same size and voltage. But some attention must be given to the location of the various portions of the secondary, so that when all the secondary is in circuit, and also when only fractional portions are in circuit, these portions may be located with reference to all of the primary windings so as to have little magnetic leakage, and therefore good regulation. With moderate currents this form of regulator is the most efficient and cheapest, as its construction is that of a simple transformer and only the needed amount of secondary is in circuit at any time. The switch introduces the only complication and limitation in its use.

The difficulty of making a switch that will be durable has been well solved for a current that does not exceed 250 amperes, voltages not above 5,000 or 6,000, and the voltage per step not above 30 to 50.

It is evident that the switch must pass from one contact to the next without directly bridging the intervening space; otherwise one section of the secondary will be short-circuited and so heavy a current will flow as to cause a vicious arc when it is broken, even if the short-circuit is not on for sufficient duration to overheat the windings. When the current does not exceed 150 amperes, or the voltage between steps does not exceed 30, this short-circuit can be avoided in a very simple manner by making the moving blade just a little narrower than that necessary to bridge between contacts, and by providing any form of automatic trip that will quickly snap the blade from one contact to the next. Under these conditions the continuity of the current will be maintained through the arc that bridges the slight break, and the counter electromotive force of this arc will prevent any considerable current circulating in the section of the winding short-circuited by it.

With larger currents, or higher voltages between steps, the arc cannot be depended upon as a preventive against short-circuiting adjacent sections; the moving contact arm must be made in two parts, insulated from each other but joined through a resistance or reactance and connected to the feeder from this preventive resistance or reactance through its middle point. Such reactance or resistance suitably proportioned and connected in this manner will avoid the necessity of breaking any current at a given output of the regulator; that is, the potential generated across the reactance by the flow of the current through it can be made, with a given current, to equal the voltage between steps. Consequently when the blade leaves one of the contacts there will be no difference of potential between it and the terminal that it has left, and therefore no arc. The switch must, however, operate under all conditions of load, and therefore it is not possible to adjust for no arcing except for one definite current. With the best possible proportioning there will be arcing enough gradually to destroy contacts capable of carrying heavy currents when an attempt is made to use this form of switch for heavy duty. When it is desirable to use the switch type of voltage control for these larger currents, therefore, it becomes necessary to use separate contacts for carrying and breaking the current. One excellent way of accomplishing this is to have two electrically operated switches or contactors in series with each half of the rotating switch whose operating circuits are so connected to a small contact device on the main switch as to open the auxiliary contactor and interrupt the current to either half of the rotating switch just before it breaks contact, and again to close the circuit just after it has made contact with any of the various stationary contacts. With this arrangement all the arcing will be removed to the auxiliary contactor switches which may be made very heavy and with easily replaceable contact surfaces. Regulating switches so designed have successfully manipulated 320 amperes with 120 volts per step.

It is evident that the range of control of a feeder regulator can be doubled if the mean of the desired voltages on the feeder or feeders be maintained on the bus bar, and the regulator used both to increase and decrease this voltage. The transformer type of regulator can be made to operate in this manner by adding to the rotating switch, which enables any portion of the secondary to be thrown in circuit, an auxiliary switch that will reverse the polarity of the primary winding after the switch has been once over its range. The switch required for this reversal is not a difficult one to design, even for quite high primary voltage, since the reversal is made only when the secondary switch is on the zero point of the dial, and when, therefore, there is no current flowing in any portion of the secondary winding. Under these conditions the primary carries only magnetizing current, which, on a regulator of 50 kw. or smaller, is a current easily handled. A typical form of this type of regulator is shown in Fig. 1.

Induction regulators. The induction or magnetic shunt type of regulator differs from the transformer type of regulator in that all the primary and secondary windings are constantly in use. Different types vary the secondary voltage either by moving part

FIG. 1.—Switch type of feeder regulator with reverser.

of the iron core or one of the windings, or one of the windings and part of the core; the whole or any part of the flux generated by the primary threading the secondary according to the position of the moving part. One of the forms is interesting because of its simplicity, and because of its early development. It consisted of a U-shaped core with a primary winding around the center leg of the core, the length of the primary coil being only about one-third the length of the core. The wire space was long and narrow, so that the portion on the core which projected beyond the primary winding formed an air-gap of moderate reluctance even when an inch or more in width. Concentric with the primary coil was a secondary coil, having the same length of layer, to which the circuit was connected by flexible cables. By means of long screws engaging with nuts on the ends of the secondary coil, the secondary was moved along in the direction of the axis of the core from the position where it entirely covered the primary to a position at the open end of the core. When the secondary covered the primary there was little magnetic leakage, and the full secondary voltage was obtained. As the secondary

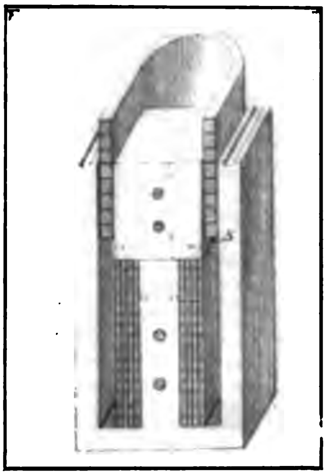


FIG. 2.—Induction regulator with movable coil.

was withdrawn from the primary, a larger and larger percentage of the flux crossed the air-gap rather than thread the secondary coil, until, when the secondary coil was fully withdrawn, practically all the primary flux was driven across the air-gap in the space between the primary and secondary. A reversing switch in the primary gave the secondary a double range of control. This form of regulator was developed in 1891. It is shown diagrammatically in Fig. 2. A considerable number of these are installed in that historic early transmission of power from Willamette Falls into Portland, Oregon, and are in service to-day. I mention these as being, as far as I know, the earliest successful attempt to build feeder regulators of the induction type. This form was somewhat objectionable in that a rectilinear motion of coils or core is always more difficult to arrange for mechanically than a rotating motion; and, secondly, because the air-gap must be large to allow the secondary coils to move through it, consequently the magnetizing current tends to be greater than in other types where the air-gap may be very much less because the moving coils do not pass through the air-gap.

The second type of induction regulator developed had stationary primary and secondary coils located at right angles to each other, and a cylindrical core through which these coils

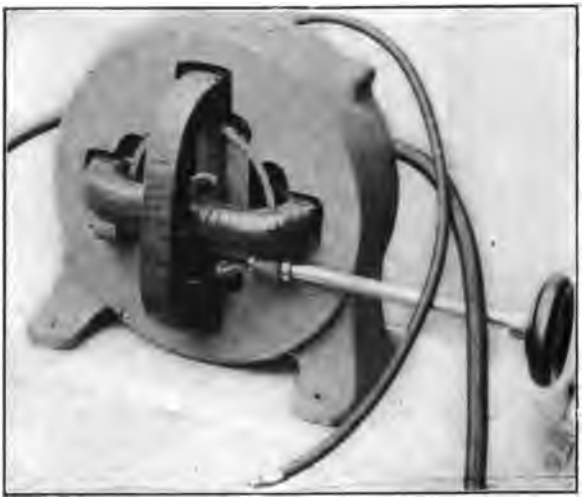


FIG. 3.—Induction regulator with movable core.

passed. The center portion of the core could be rotated in such a way that any desired part of the flux of the primary coil would pass through the secondary coil.

This form of regulator, see Fig. 3, is due to Dr. Steinmetz, and was really the forerunner of all the forms of induction regulators that have become so successful and useful. The air-gap in such a construction can be made very small, even less than in an induction motor, because there is no rapid rotation or wear of bearings to provide for, and consequently the magnetizing current need not be greatly in excess of that taken by a transformer with no air-gap. The particular form first developed was limited in its capacity, due to the fact that the primary and secondary were so far from each other that the mutual reactance was high, and inherent regulation consequently poor.

The third form of induction regulator to be developed historically resembles an induction motor in its general construction; the primary corresponds to the field and the secondary to the armature winding of an induction motor, not of the squirrel-cage type, but one with windings that are insulated, the terminals of which are brought out for purposes of control. This form of winding, with its many slots per pole and with only a very slight air-gap, forms a transformer having low mutual reactance between primary and secondary when the moving core and coils are in such position that the axes of the primary and secondary coils coincide. As the core is moved so that these axes are out of line, not all of the primary flux cuts the secondary winding, and the induced voltage in the secondary gradually falls, until, when each secondary coil is midway between adjacent primary coils, there is no voltage induced in the secondary. When the secondary winding is midway between the primary winding, however, it will, if it is carrying current, set up a heavy flux of self-induction which will close itself through the adjacent core between the adjacent primary coils. The result is a poor regulating device except at or near the full load position. This objection was nicely overcome by Dr. Steinmetz, who placed between each primary coil a distributed winding short-circuited on itself, so located that it is cut not by the primary flux but by the secondary self-induction flux just in proportion as the secondary moves away from the influence of the primary flux. Both the regulator with the single coil windings and that with the distributed windings can evidently be used to either raise or lower the voltage by simply rotating the moving core and coil through the angular distance corresponding to the polar pitch.

All forms of regulators so far described have been for use on single-phase circuits only. The distributed winding just described lends itself perfectly, however, to three-phase winding, and is much more efficient in three-phase than in single-phase circuit, because with the three-phase connection the short-circuited winding may be dispensed with, since the winding of the other phases naturally falls in the same location as the short-circuited winding, and acts with equal effectiveness in eliminating the flux of self-induction in the adjacent secondary.

With a multiphase winding, a secondary coil in one phase, as it passes out of influence of a given primary coil, passes into the field of a primary coil in the next phase. The result is a constant voltage generated in each of the secondary coils regardless of their position with reference to the primaries. The phase relation between this secondary voltage and the phase of the feeder circuit, with which it is in series, however, varies directly as the secondary coil is displaced with reference to the primary coils of the same phase. The result is that while the voltage measured across the secondary remains constant, its effect on the circuit, due to the phase displacement, varies from zero to maximum, and exactly as if the voltage and not the phase relation varied.

Feeder regulators of the induction type have for several years been built in all sizes from 3 kw. to 1000 kw. The larger sizes are seldom used for what could be properly called feeder regulation although some having several hundred kilowatt capacity have been built for the control of high-voltage feeder lines delivering current to sub-stations of several thousand kilowatt capacity. Most of the larger capacity, however, especially those having three-phase windings, are used to control the voltage delivered to synchronous converters, so that the voltage on the direct-current side may vary in accordance with the requirements for bus-bar potential, or for the charging of the storage-batteries used for feeder control and storage purposes.

It is rather interesting to note, in view of the fact that induction regulators larger than 300 or 400 kw. are still quite infrequently called for, that the first induction regulator which was attempted, was built fifteen years ago, and had 450 kw. single-phase capacity.

Automatic control of feeder regulators. A feeder regulator may have ample capacity to compensate for any changes in bus-bar potential or any varying drop in the feeder, and yet the voltage at centers of distributions may be far from satisfactory in its steadiness, due to the inattention of the station attendant or to his inability to change the regulator as rapidly as the variations in bus-bar voltage or feeder losses may require. Moreover, if an attempt is made to overcome this weakness by additional attendants, the increase in operating expenses occasioned thereby may be very considerable.

Many plants now receive current from large power systems, a large part of whose output is absorbed by railway and other motors, whose demands for current vary so rapidly that even if an attendant were constantly watching the voltmeter, in the attempt to adjust the feeder regulator to compensate for the changes in bus-bar potential, he would find it entirely impossible to control the voltage as rapidly as is necessary for good life or good service with incandescent lamps.

It was not, therefore, until about two years ago, when the first successful devices were developed for automatically operating various forms of feeder regulators, that feeder regulators assumed their proper and important sphere in electrical distribution of power.

It will be recalled that various more or less successful attempts have been made in the past to control automatically the potential of generators. The first really successful of these was perhaps the Edison regulator for direct-current generators. The device consisted simply of a rheostat with a special form of rotating arm and contact device moving through a range of only 45 degrees or so, and controlled by solenoids in shunt with the commutator of the machine. It was reasonably successful in isolated plants, but did not admit of satisfactory operation on large plants where the generators had to be operated in multiple.

Various forms of mechanism for automatically controlling the field rheostats of generators have been developed and are used with moderate success, but they are all too slow in their mechanical operation, and many of them too complicated to be extensively used.

In 1891 or 1892 Elihu Thomson made the first attempt to use the only principle of automatic control of generators that has ever proved itself entirely equal to meet all requirements. He met the problem with characteristic boldness of method. Instead of working on a rheostat which must of necessity be slow in operating, he used a series-wound exciter, and brought out two taps from the field winding of this exciter so located that when these taps were joined together a sufficient number of the series turns of the field were short-circuited to give the minimum voltage required to excite the generator under no load. When this short-circuit was removed and the full winding was in circuit, them aximum voltage necessary for the excitation of the generator under its greatest designed overload would be generated. He then designed a special form of contact-making voltmeter capable of very rapid response to changes in voltage, and connected the two taps from the field of the exciter to two contacts of the voltmeter. When the voltage was too high on the generator, the voltmeter's contacts would short-circuit this portion of the exciter's field; when it was too low it would remove this short-circuit. Except at no load and full load, of course, there was no position of equilibrium for the voltmeter. It therefore vibrated rapidly, making and breaking the shunt-circuit on the exciter's field, and gave an average voltage dependent on the percentage of time that the contacts were closed or open. The device would undoubtedly have been immediately successful if it had been first tried on a moderate size of generator requiring so small an exciter that an ordinary silver or platinum contact on the voltmeter would have stood up under the constant making and breaking of the circuit. Unfortunately, however, it was tried on an 80-pole, 400-kw. slow-speed single-phase generator. This was a very large machine for those days, and 30 kw. or so were required for excitation. It was found necessary therefore in order to protect the contacts, to have an exciter for the exciter, and to operate the voltmeter on the small exciter.

With these three magnetic systems operating in succession there was just enough lag between the operation of the voltmeter and the response in the voltage of the alternating-current generator to make the operation a failure; that is, the voltage of the generator surged over a range of three or four per cent. at a frequency of six to eight cycles per minute. It was not until Mr. Tirrill took up the problem along the same lines several years later that this ideal method of controlling the voltage of a generator was successfully perfected.

The Tirrill method differs from the Thomson method only in that the vibrating contact short-circuits a resistance in series with a shunt field exciter, and that the voltmeter is provided with a special alloy of iridium for the contact points; this makes it possible to handle current and voltage quite impossible to handle with any other metal when the circuit is so rapidly made and broken. The wonderful success of the Tirrill regulator in controlling all forms and sizes of generators is doubtless well known to us all.

A slightly modified form of the Tirrill regulator has been developed and applied to the control apparatus of feeder regulators, and as a result their value and field of usefulness were immediately increased many fold.

Of all the various forms, the induction type of regulator, free as it is from all moving contacts, lends itself most readily to automatic control. A small motor is readily attached to the same mechanism that is used for hand operation. A switch capable of starting, stopping, or reversing this motor can be easily operated magnetically, and this in turn be controlled by a modified Tirrill contact-making voltmeter. Fig. 4 shows an automatically operated regulator of this type.

FIG. 4.—Induction regulator with distributed windings, movable core and coils, automatically operated.

When the changes of the voltage of the feeder, due either to varying load or to varying bus-bar potential, are fairly slow, this method of automatic control leaves little to be desired. When somewhat greater rapidity of control is needed, this can be accomplished by keeping the motor in constant rotation and using magnetic clutches whose excitation is controlled by the contact-making voltmeter, thereby saving the time for the motor to come up to speed.

Many feeders have such rapidly varying loads, furnishing current to elevators or hoisting machinery, for instance, or they are operated from bus-bars whose potential changes so rapidly, that some form of regulator, in which it is not necessary to move so great a mass as must be moved in the induction type regulator, becomes necessary. Under these conditions one naturally turns to the transformer type of regulator, where the only moving part is the rotating arm of the switch. But the

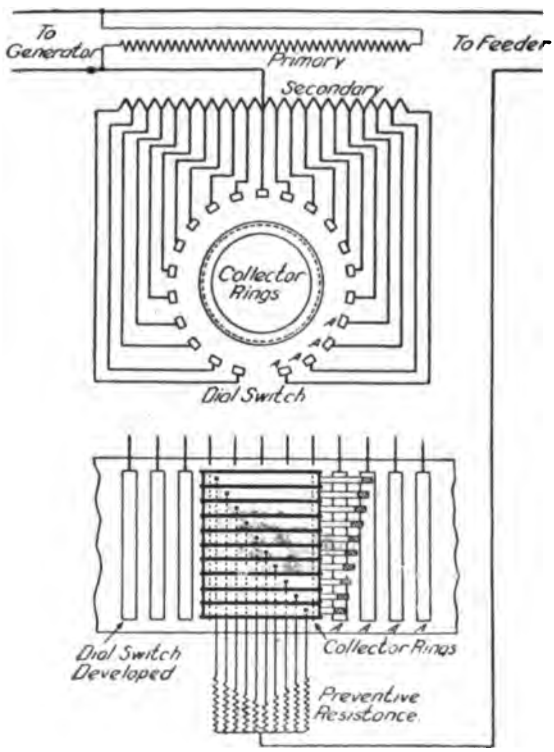


FIG. 5.—Connections of switch type of automatically operated regulator.

forms of these switching devices which have been previously used offer an almost unsurmountable mechanical difficulty to rapid rotation in the step-by-step automatic snap motion that is required in passing from each step to the next.

A new form of such switch, however, has been successfully worked out in the solving of this problem. The details of this switch will be best understood by referring to Fig. 5, but can perhaps be generally understood from the following description:

The moving element consists of a series of fingers, the majority of which are always in contact with two of the stationary contacts. Each finger is connected to a corresponding stationary collector ring by means of a suitable brush, and each collector ring is connected to the line through a preventive resistance. The individual fingers do not span the spaces between the adjacent contacts, but the arrangement of the combination is such that when the center of the top finger is on the center of one contact, the center of the bottom finger will be on the center of the next contact, the intermediate fingers being spaced so that the centers of all are on a straight line, joining the upper and lower fingers. The resistances which connect the several fingers to the line not only prevent excessive exchange currents as the fingers pass from contact to contact, but cause the change in the secondary voltage to be gradual rather than in steps. The moving member may therefore be left in any position whatever, and a much closer adjustment of voltage is obtained than by the switch which passes in one movement from each step to the next.

The moving parts of this form of switch can be made so light and compact that a very small motor, acting through suitable gearing, will move it from rest round the entire circumference of the contact points, covering the entire range of control of the regulator in from two to three seconds. Such a device, operated from a constantly revolving motor by means of the magnetic clutch and the rapidly vibrating contact-making voltmeter, cannot, of course, forestall needed changes in voltage, but it comes about as near doing so as can be imagined when parts having any appreciable mass are to be moved. Fig. 6 shows two simultaneous charts, the first showing the line potential and the second the feeder potential after having been regulated by this type of regulator. We find that with such a device, a source of varying potential which no one would think of using for any other purpose than the operation of motors, becomes available to give entirely satisfactory incandescent lighting service.

So far no attempt has been made to develop this form of regulator for handling much more than 150 amperes. The slight wear that must take place on the rapidly moving parts, and the generally increased complexity of the mechanical parts, makes it desirable to use the induction type of regulator for automatic work whenever it will fill the requirements as to speed; where it will not fill these requirements there need be no hesitancy in making use of the more sensitive rotating switch type, provided the work comes within the range of its capacity. Fig. 7 shows a regulator of this type.

Just a few words as to how the automatic regulator may be adjusted to give constant potential at the center of distribution

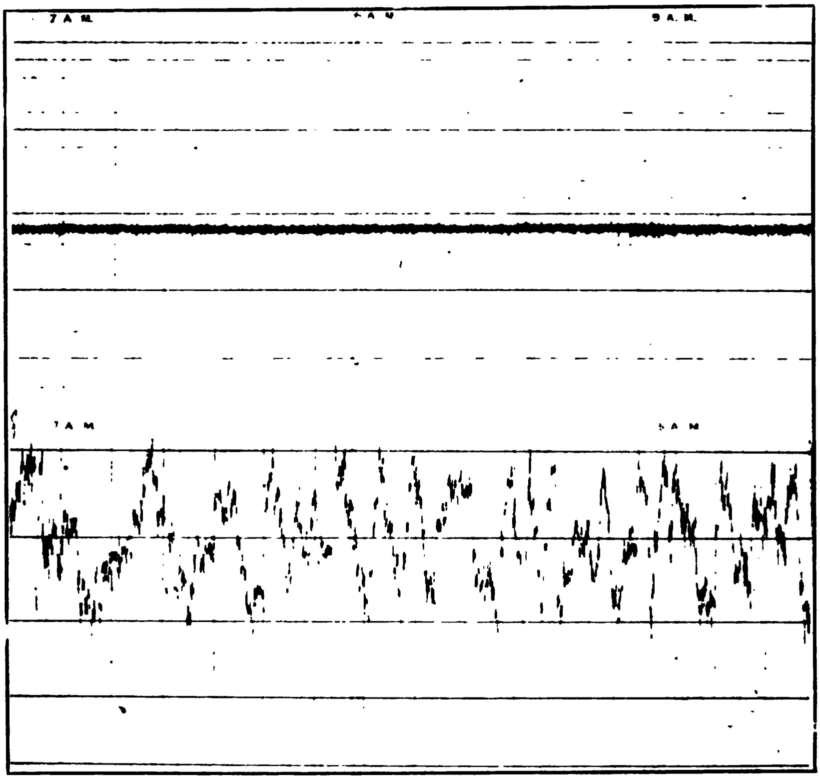


FIG. 6.—Charts showing the operation of the automatic switch type of regulator.

rather than at the station. The first method that would probably occur to any one would be to bring back from the center of distribution potential wires which would be connected to the terminals of the contact-making voltmeter. This is not so simple or satisfactory as it might seem, for the expense of running the wires is by no means negligible, and unless they are carefully crossed to avoid induction, current in the feeders might induce sufficient voltage to make the voltmeter's operation quite inaccurate. A simple means of accomplishing the result, which is often all that is necessary, is to have on the winding of the contact-making voltmeter an auxiliary winding connected to the secondary of a suitable current transformer, whose primary is in series with the feeder. If the windings of current transformer and voltmeter are properly proportioned and connected so that the current from the current transformer opposes the

FIG. 7.—Automatically operated switch type of regulator.

current in the shunt coil, the voltmeter will become differential in its action to any desired extent and will cause the feeder regulator to give a voltage which will increase the voltage across the feeder in proportion to the drop in the feeder. This simple method will, however, only increase the voltage in proportion to the current in the feeder. But this is not all that is necessary, as the drop in the alternating-current feeder is not only proportional to the current it is carrying, but is also roughly inversely proportional to the power-factor of this current. To obtain constant potential at the center of distribution under all conditions of load, therefore, it becomes necessary to feed the differential winding of the voltmeter from a source of voltage that will be proportional to the voltage lost in the feeder under all conditions. This is nicely accomplished by a device commonly known as a line drop compensator, which consists simply of adjustable reactance and resistance placed in series with the secondary of a current transformer placed in the feeder. By adjusting the reactance and resistance in this device so that they bear the same relation to each other as do the reactance and resistance of the feeder to be controlled, a source of voltage which will give the desired effect on the differential winding of the contact-making voltmeter will be obtained, and absolutely constant potential will be maintained at the center of distribution under all conditions of current and power-factor.

The improved quality of the service which can be given when suitable automatic potential regulators are made use of, and the increase in the life of the incandescent lamps which results therefrom, should be sufficient inducement to make the installation of automatic control well-nigh universal. There is perhaps a more direct effect accomplished by their use which would appeal more strongly to many station managers, simply because the economies resulting are more evident. I refer to decreased station attendance.

The time is fast coming when nearly all service feeders will emanate from sub-stations rather than generating stations, these sub-stations being supplied from either distant water powers or great steam generating stations. In fact, a large proportion of electrical power is so distributed already. Such stations frequently have no rotating machinery, and if they do it is usually of so simple a character that it needs very little attention. Watching the voltmeter on the various feeders, and adjusting the feeder regulators, therefore, becomes almost the sole work of the attendants in such a sub-station.

One attendant can satisfactorily watch only one voltmeter, and adjust one feeder regulator at a time, and therefore if reasonably good service under varying load or varying potential received at the sub-station is to be accomplished, it is necessary to have an attendant for almost every feeder, and even then the service may be very poor. It is in eliminating the necessity of these attendants, therefore, that the greatest direct economy can be accomplished by automatic regulators.

DISCUSSION ON "ALTERNATING-CURRENT FEEDER REGULATORS." TORONTO SECTION, FEBRUARY 20, 1908.

R. G. Black: We have used regulators of all the types described and have found them to give good results in practical operation. The automatic regulator is particularly interesting inasmuch as it keeps the voltage at the centre of distribution constant and takes a great deal of work off the station operator.

I am sorry that Mr. Moody did not discuss the relative merits and disadvantages of several other types of regulators; for instance, a type consisting of a transformer, the low-tension side of which is in series with the line, and the high-tension side energized from an auto-transformer placed across the line. By means of taps brought out from the autotransformer, the voltage on the primary of the series transformer is raised or lowered and the regulation thereby effected without breaking the heavy current which is flowing in the circuit. In this way a gradual raising or lowering of the voltage may be effected, and it is the writer's opinion that there will be very much less wear at the shifting contacts. However, there may be other disadvantages which more than counterbalance this feature.

The ease with which a feeder regulator makes it possible to regulate a numbe. of alternating-current circuits, from one bus-bar, stands out in great contrast with the low-tension, direct-current system, which necessitates having two or more sets of bus-bars each energized by separate generators and then switching devices to transfer the feeder from one bus-bar to another.

J. Kynoch: A large number of lights and some motors were required in a large building, and the only available source of supply was feeder to a suburban railway. It was found that the voltage at the end of this feeder varied from 350 to 575. It was proposed to use a direct-current motor-generator set, the motor being wound for 500 volts normal, and the generator for 220 volts. In order to keep the speed of motor and voltage of generator constant, a Tirrill regulator was arranged to be placed on the fields of each machine, the relays on the motor fields being so connected that as the voltage of the railway feeder changed, the field strength of the motor would be varied, and in this way the speed kept constant. The only other requirement was, that the design of the motor should be such that the motor should be capable of giving the required output at the minimum voltage for such length of time as such low voltage may exist.

The regulator on the generator was applied in the usual manner, and was arranged to give either constant terminal voltage at the generator or a constant voltage at the end of main lighting feeder. In this way an eminently satisfactory control of voltage was obtained from a source which under ordinary circumstances would be quite impracticable for incandescent lighting.

Another way to meet the above conditions would be to apply a Tirrill regulator to the generator fields only, and allow the motor speed to vary with changes in feeder voltage. This, of course, needs a specially designed generator to give the normal voltage at minimum speed, and also means using a field rheostat of very high resistance, in order to reduce to normal, the high voltage at maximum speed.

Mr. Moody refers to the possibility of voltage regulation by using capacity, such as the leading current from synchronous motors. I should like to enlarge upon this as follows: The voltage regulation of alternating-current power feeders having considerable reactance can be accomplished by applying a Tirrill regulator to the exciter of a synchronous motor connected to the ends of such feeder. In this way not only practically constant potential can be maintained, but also high power-factor due to the regulator varying the excitation of the synchronous motor and thus causing the same to supply leading or lagging current as the voltage of the circuit drops or increases, respectively.

This scheme is especially valuable on 60-cycle transmission lines as the inductive losses on such lines are usually considerable, and consequently the line regulation is very much worse than on a 25-cycle circuit carrying the same class of load. Of course, in order for a motor successfully to regulate a transmission line, it would be necessary for the motor to carry a reasonable proportion of the load, probably in the neighborhood of 30 per cent., but a larger proportion would be better. It is, of course, assumed that Tirrill regulators would be connected to the generators at the power station, so that the motor would not have to do an abnormal amount of regulation.

R. S. Kelsch (by letter): One Canadian company has a number of induction regulators in service, some of which have been in operation almost ten years. These regulators vary in size from 40 kw. to 800 kw. capacity each. There are a number of 40-kw. oil-cooled regulators used in connection with synchronous converters, and several 40 kw. air-cooled regulators used in connection with three-phase feeders. The company also has two 350-kw. air-cooled and one 800-kw. three-phase regulators used in connection with sub-station work.

In the sub-station, the power is received at a voltage which varies according to the demand made by the different sub-stations on the line. In one instance the power is received at approximately 11,000 volts stepped down to 2300 volts. This pressure is used for power service. For the lighting load, the same power is delivered to a second bus-bar through a 350-kw. regulator, which automatically maintains the voltage required, depending upon the load on the lines.

The 40-kw. regulators are used for individual feeders, where the load varies considerably. For example: the company has a feeder three miles long, which, during the day time delivers power to a large induction motor for pumping purposes. The load on this line varies during the 24 hr. from 10 to 100 per cent. and the power-factor changes from 80 to 95 per cent. It would be impossible to handle this business without induction regulators.

In one of the sub-stations, 14,000 h.p. is received, and a large portion of the power distributed locally, the balance distributed to a considerable distance. The same pressure would not suit both purposes, but the 800-kw. induction regulator makes it possible to receive a pressure suitable for local distribution, and, at the same time, transmit the balance of the power a considerable distance, delivering it at the required pressure.

During the ten years these regulators have been in service, there has not been one accident, failure to work, or interruption of any kind due to the regulator, notwithstanding the fact that most of the regulators are exposed direct to the line.

A paper presented at the 226th Meeting of the American Institute of Electrical Engineers New York, March 13, 1908.

NOTES ON ELECTRIC HAULAGE OF CANAL BOATS*

BY LEWIS B. STILLWELL AND H. ST. CLAIR PUTNAM

The following notes are based upon the results of tests conducted by the authors during the autumn months of 1907 on a section of the Lehigh Canal near Mauch Chunk, Pennsylvania. The object of the tests was to determine:

a. Pull required to propel canal boats at various speeds and with varying numbers of boats in tow.

b. The relative merits, for the purpose contemplated, of locomotives supplied by trolley and operating upon a track of 42-in. gauge, and a monorail system.

c. The best speed and length of tow as fixed by physical conditions.

d. The power required to operate the canal between Coalport and Bristol.

e. The equipment required for such operation.

The data presented in this paper are included under the headings " a ", " b ", and " c " of the foregoing summary.

The upper section of the canal from Lock No. 2 to Coalport, a distance of 10,095 ft., is equipped with the " Locomotive System ". The plan and profile of this section of the canal are shown in Fig. 2. On this section an ordinary mining locomotive is used. Two locomotives were tested, each weighing under test conditions 16,000 lb. without testing instrument equipment and crew. Each locomotive is equipped with two

* By the courtesy of Mr. W. A. Lathrop, President of the Lehigh Coal & Navigation Company, for whom the tests were made, we are permitted to present to the Institute such results of our investigation as are not purely local in their significance but comprise data more or less applicable to the general problem of electric operation of canals.

direct-current motors of 28 h-p., operating on 500-volt trolley circuits. The locomotive wheels are 28 in. in diameter and gear-ratio of 69/15. The wheel-base is 44 in. The outline drawing of this locomotive is shown in Fig. 6.

The locomotives were operated on a track of 42-in. gauge and ballasted on the river section with broken stone, elsewhere with gravel. Forty-pound rails were used. The track was uneven and comparatively rough.

On this section, two levels of the canal, aggregating 5600 ft. in length, were in the open river exposed to the river currents. The voltage of the trolley circuits was varied to obtain various towage speeds; an experimental generating plant, connected as shown in diagram No. 9, being used as a source of power supply.

The section of the canal from Lock No. 3 to Lock No. 7, a distance of 10,555 ft., was equipped with the " Monorail System " illustrated in Fig. 3. On this section three traction machines were used. These machines are hereinafter designated " Tractors." Two of these tractors (Nos. 1 and 2) were manufactured in this country. The electric equipment of each comprised one direct-current 40-h.p. motor. The gear-ratio was 5.78 to 1; diameter of wheels 12 in., and length of wheel-base 42 in. The construction is illustrated in Fig. 7. The ratio of leverage on lever wheels was 4.7 to 1; that is to say, the lower wheels are pressed upward against the lower face of the rail with a force 4.7 times the drag on the tow line. The adhesion of the machine, therefore, is a function not only of its weight but also of the pull which it exerts. Each tractor weighs 6,450 lb., and, under test conditions with instruments and crew, 7,350 lb. Tractor No. 3 was manufactured in Paris, and equipped with one 25-h.p. mining motor. Its wheels are 11.25 in. in diameter, gear-ratio is 3.4 to 1, and wheel-base 42 in. The general design is the same as that of Tractor No. 1 and is shown in Fig. 7.

Owing to the fact that the frame of this tractor had not been designed to receive a motor of the exact dimensions of that with which it was equipped, it was impossible to locate the motor in its proper position; it was necessary, therefore, to use 500 lb. counterweight to secure equilibrium of the machine. The weight of the tractor complete was 5,093 lb.; including counterweight, test apparatus, and crew, 6,493 lb.

The mechanical construction and workmanship of Tractor 3 made it superior to Tractors Nos. 1 and 2, as was evidenced

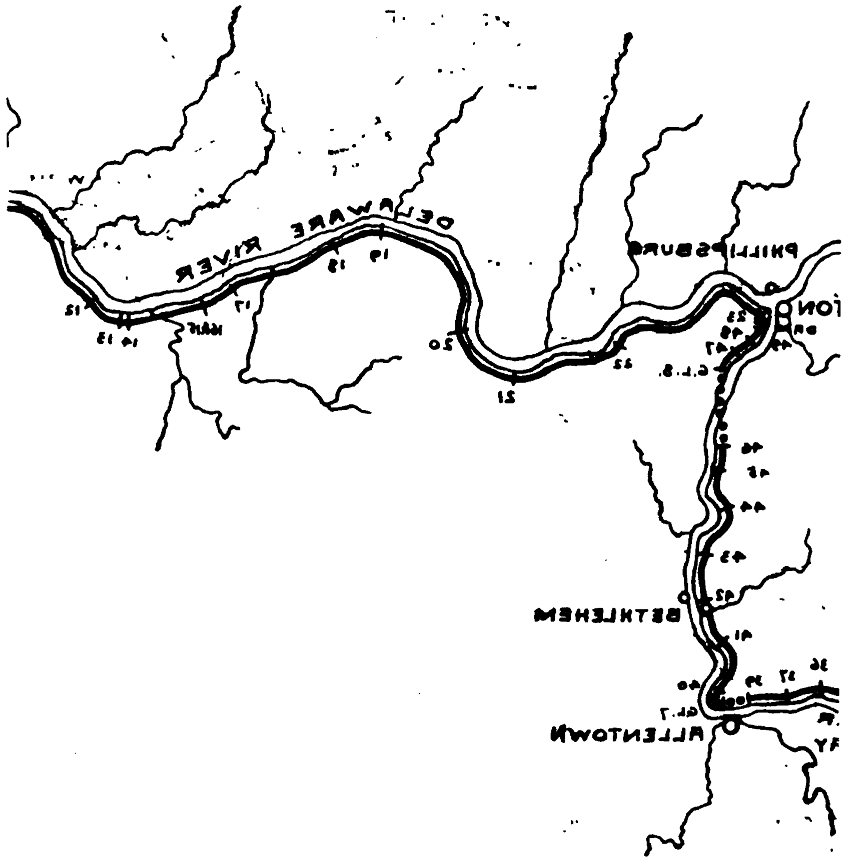


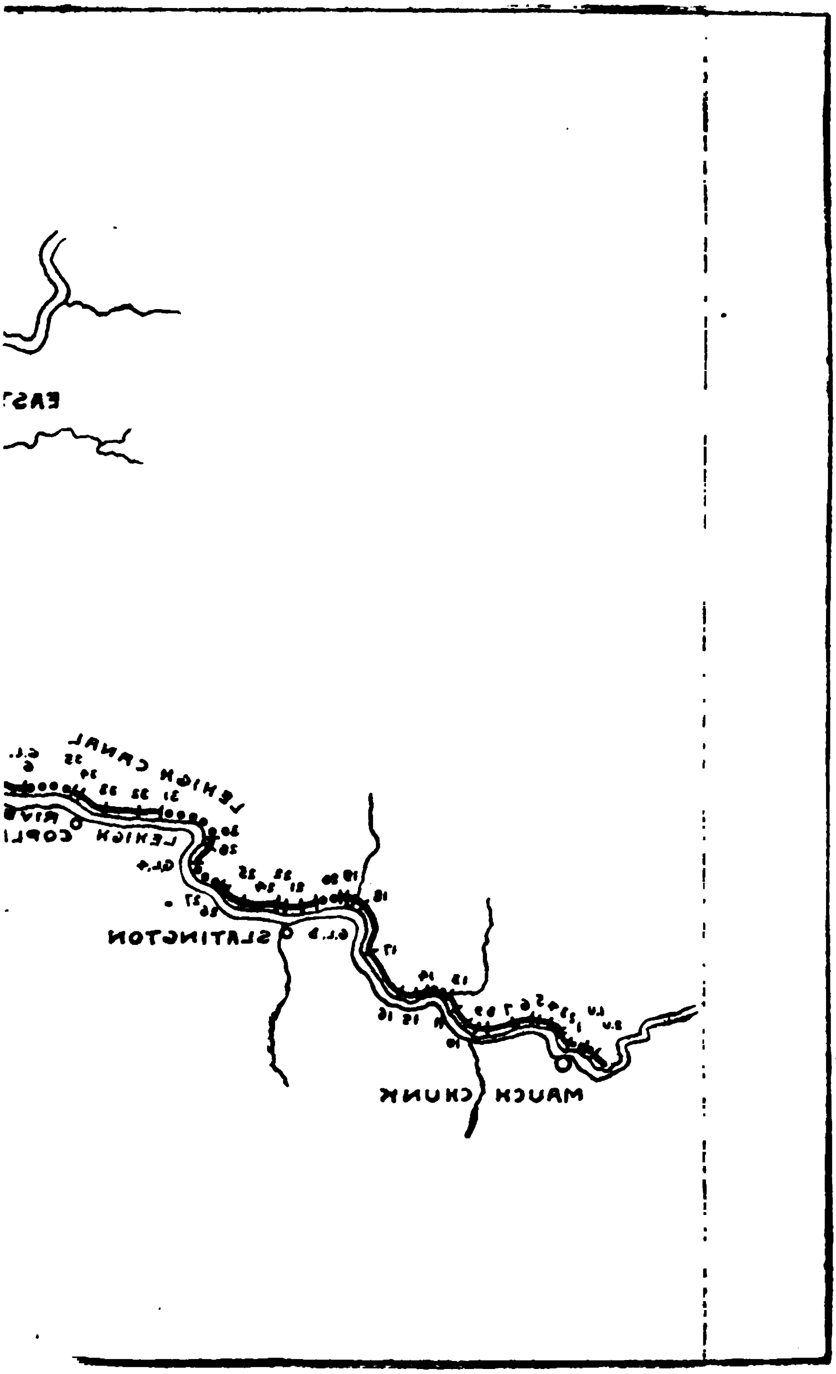
FIG. 1.

PLAN

LEHIGH AND DELAWARE (CAN

CANAL SECTION(S)

RIVER SECTION.



not only by inspection but also very conclusively by the results of tests. In our comparative calculations of power required respectively by the locomotive and monorail systems, therefore, we have used the results obtained in using Tractor No. 3.

The tractors were operated upon a monorail supported at a height of 4 ft. above the ground by steel posts placed at intervals of 18 ft. The rail, as used in the installation at Mauch Chunk, is an ordinary 10-in. I-beam weighing 75 lb. to the

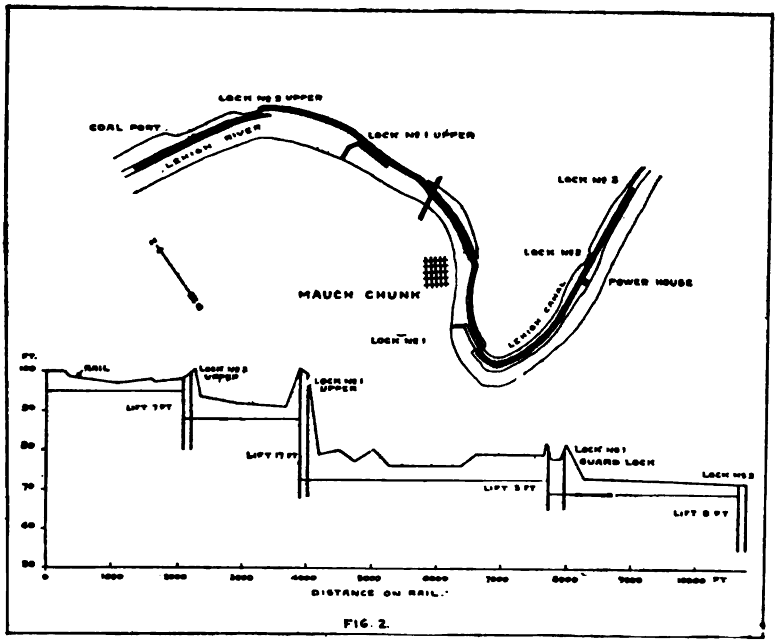


Fig. 2

yard. The monorail with supports and braces complete weigh 120 lb. per yard and is erected along the canal outside the tow-path. The construction is illustrated in Fig. 4.

A fourth tractor, No. 4, built in Paris, was also subjected to certain tests. This machine, without testing crew and instruments, weighed 3,465 lb. It was equipped with one direct-current. 500-volt motor of 15 h.p. The diameter of wheels was 12.75 in. and the wheel base 24 in. This machine is illustrated in Fig. 8.

For this smaller machine a section of monorail tract 1,200 ft.

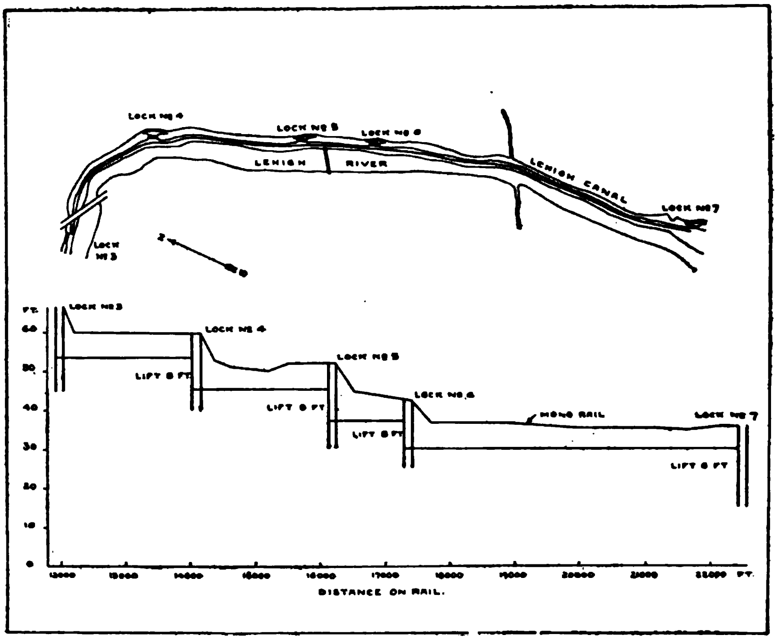

LEHIGH RIVER
LEHIGH CANAL
MONO RAIL
DISTANCE ON RAIL.

Fig. 3

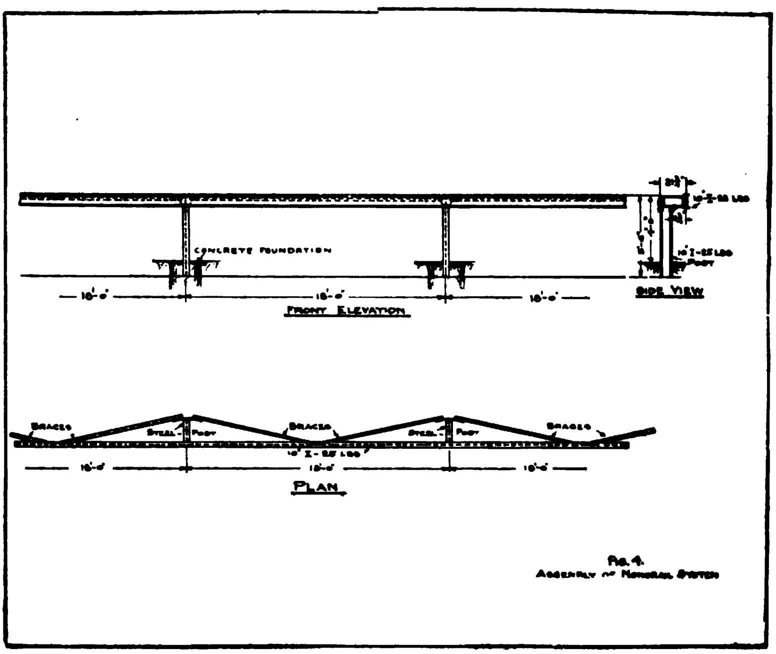

CONCRETE FOUNDATION
FRONT ELEVATION
SIDE VIEW
PLAN

Fig. 4

long was erected on wooden posts between Locks Nos. 2 and 3. The rail in this case was a 7-in. I-beam, weighing 45 lb. per yard, and was erected at a height of 4 ft. from the ground. It was not deemed necessary to undertake complete tests of Trac-

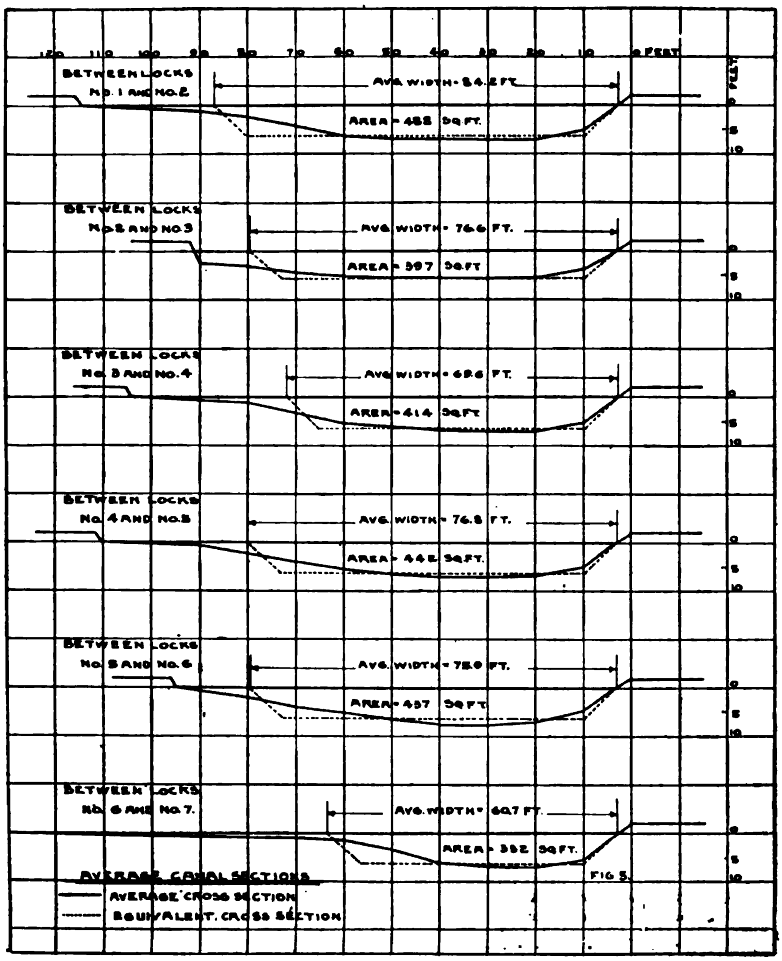


Fig. 5

tor 4, as certain preliminary tests showed that the machine was not adequate in mechanical strength and power equipment for the service. Volt and ampere readings were made, however, in connection with dynamometer readings and from these the approximate performance of the machine was determined.

The following instruments were used in making the tests:

Direct-current graphic recording wattmeter with time attachment. This wattmeter was also equipped with a signal pen used to record distances and special points by means of a push button. Weston ammeter. Weston voltmeter. Three spring dynamometers. Two integrating wattmeters used to measure respectively the energy delivered to the monorail and locomotive sections.

Distance marks were located at distances of 52.8 ft. along

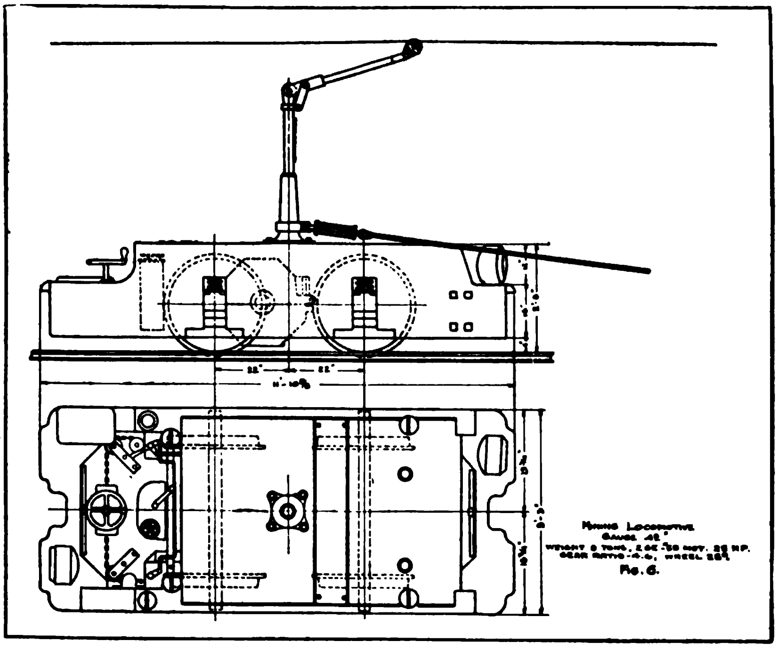


Fig. 6

the track. As each point was passed by the machine undergoing test, a push-button record was made by the signal pen in the graphic recording wattmeter and at the same instant the voltmeter and dynamometer were read by the test crew. In addition, during one complete run, the angle formed by the towrope and the center line of the track was determined at each distance point by measuring the distance from the center of the track to a fixed length of tow-line. All test results are corrected for this angle, and the tow-line pulls stated are the

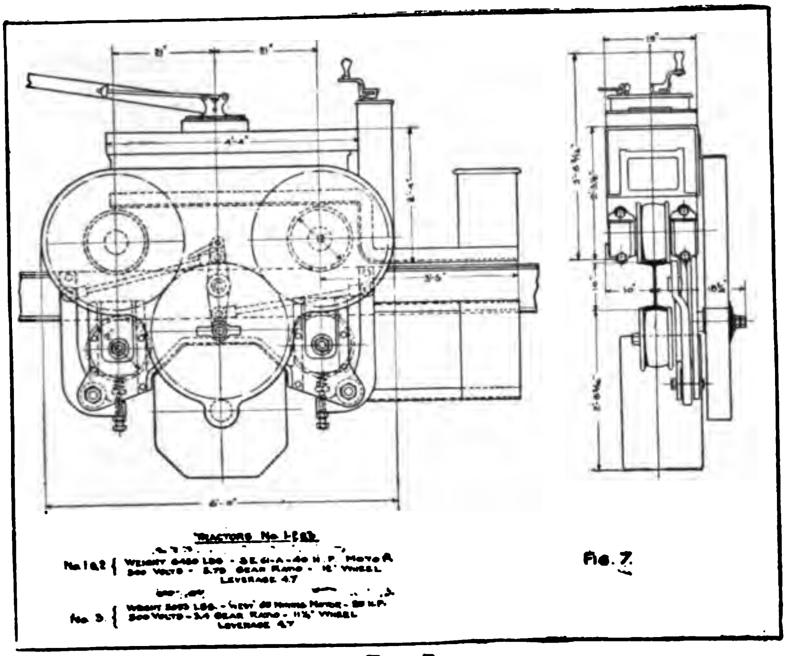

Tractors No 1-2&3
Leverage 4.7
Leverage 4.7
Fig. 7

Fig. 7

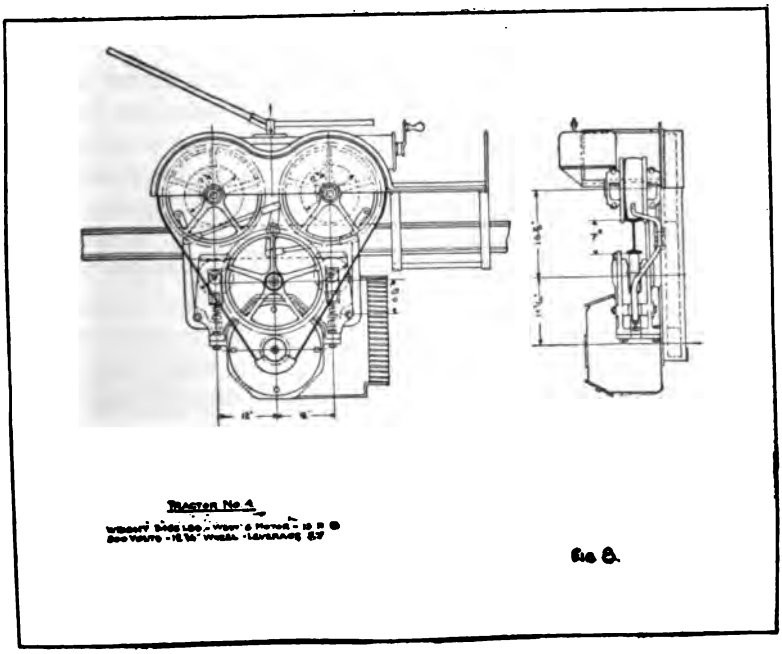

Tractor No 4
Fig 8

Fig. 8

effective pulls in the direction of motion. In the tests the tow-line was approximately 200 ft. long. Typical records such as were made in each test, are shown in Fig. 11.

Four canal boats were loaded and used in all comparative tests made. The weight in net tons, dimensions, and draft were as follows:

TABLE I

Boat	Loaded	Empty	Length	Width	Draft
1	137 tons	23.5 tons	87 ft. 6 in.	10 ft. 5 in.	5 ft. 1.875 in.
2	139 "	23.0 "	87 ft. 6 "	10 ft. 5 "	5 ft. 2.5 "
3	137 "	24.2 "	87 ft. 6 "	10 ft. 5 "	5 ft. 2.625 "
4	135 "	24.2 "	87 ft. 6 "	10 ft. 5 "	5 ft. 1.75 "

These boats in the order named were used in all four-boat tests.

Boats 3 and 4 were used in one-boat tests.

Boats 1 and 2 were used in two-boat tests. In the later tests boats 1 and 2 were equipped with the " Erie Steering Gear " hereinafter described.

In addition to tests of the four boats above referred to, the regular canal traffic was handled by the test machines on their respective sections during the months of October and November and a part of September. Complete tests were made from time to time as opportunity offered, until it was thought that sufficient data had been collected. We have found it necessary to make use of these miscellaneous tests to a limited extent only.

The velocity of the current of water flowing in each section of the canal was determined at the time the tests were made, but to obtain an average value for towing resistance, including the effect of this current and also of track grade, all tests were made in both directions over each section of the canal. The average results are used in our calculations.

Effective tow-rope pulls required. The effective tow-rope pulls as determined by dynamometer tests and corrected for the rope-angle for four-, two-, and one-boat tests, both light and loaded, are given in Fig. 12 and Fig. 13.

The following table shows the average results obtained at the average towage speeds attained in tests:

TABLE II

Boats	Weight tons (2000 lb.)	Average speed in mi. per hr.	Effective pull pounds	Constant ($C V^2 T$)
Four boats loaded	548	2.98	2200	0.452
Two boats loaded	274	3.62	1500	0.418
One boat loaded	137	4.00	1000	0.456
Four boats empty	95	4.00	1010	0.664
Two boats empty	47.5	4.20	560	0.668
One boat empty	23.8	5.00	400	0.673

In the majority of the two-boat tests, the boats were equipped with the so-called Erie steering gear. With this gear the second boat is used as a rudder for the first boat, to which it is tightly lashed. The arrangement is illustrated in Fig. 10.

The effect, so far as resistance of the water is concerned, is a reduction of approximately eight per cent. in the pull required; in addition to which saving the boats are kept in better alignment and are under better control. In the majority of the four-boat-tests, the first two boats were equipped with the Erie steering gear, but this beneficial effect as regards reduction of pull required, was apparently lost, owing probably to the effect of the drag of the last two boats, which tended to alter the position of the first two with reference to the line of motion.

From Table II it appears that for boats, such as are used on the Lehigh and Delaware canals, the effective tow-rope pull in pounds, required for any number of loaded boats, is expressed approximately by the formula $0.45\, V^2\, T$, and for empty boats by $0.67\, V^2\, T$, where V is the speed in miles per hour and T the total tons (2000 lb.). A brief discussion of required tow rope pull as related to draught and the depth and width of canal will be found in appendix.

Acceleration and Maximum Rope Pulls

Compared with electric railway operation, the rate of acceleration practicable of attainment in towing canal boats is low.

Acceleration, however, is relatively unimportant, as the time of run is long compared with the time consumed in acceleration. The greatest pull is exerted when the last control-point

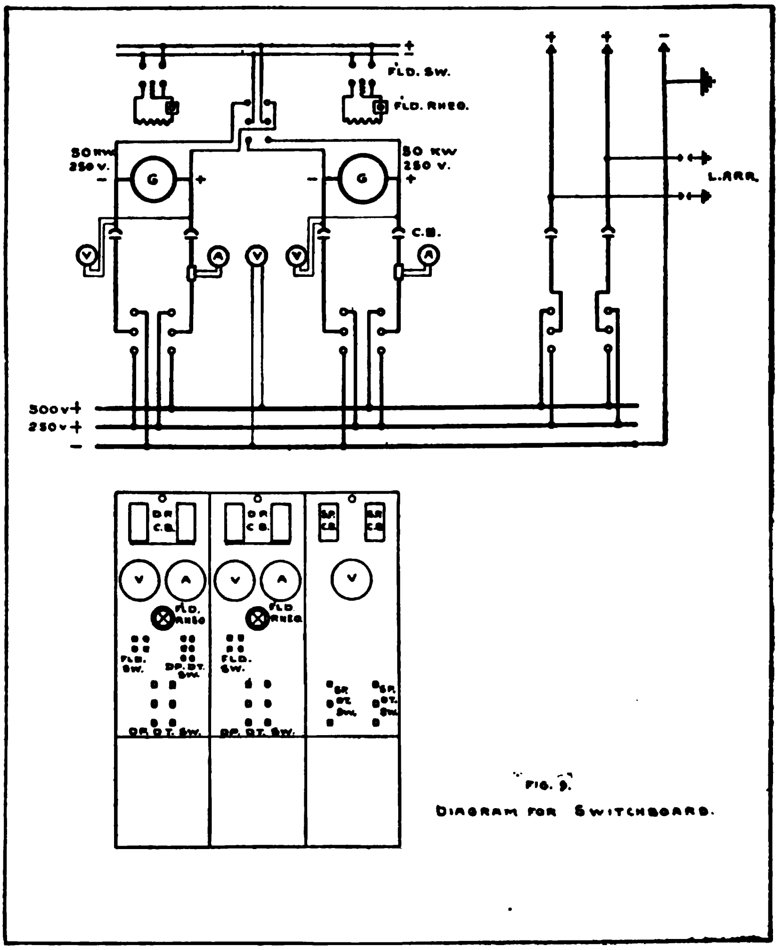


FIG. 9

is reached, but this does not greatly exceed the pull required at full running speeds.

Table III gives the maximum and average results obtained in four-, two-, and one-boat tests, both loaded and empty.

TABLE III.—Acceleration and Rope Pull

(Pulls not corrected for rope angle.)

	Acceleration miles per hr. per sec.		Pull lb. at end of acceleration		Average pull lb. running	
	Ave.	Max.	Ave.	Max.	Ave.	Max.
4 boats loaded	0.0243	0.045	2370	3100	1990	2300
4 boats empty	0.0975	0.142	1220	2100	1040	1250
2 boats loaded	0.0594	0.101	2240	3100	1500	1700
2 boats empty	0.0995	0.135	850	1150	680	1100
1 boat loaded	0.0667	0.103	1190	1800	650	1000
1 boat empty	0.1090	0.173	730	1100	625	900

Towing Machines Tested.

In most of our tests Mining Locomotive 15 and Tractors 1 and 3 were used. Comparison was made at speeds and effective pulls as nearly identical as was found practicable.

As to meet these conditions the various machines tested required different operating energy, and as change in the energy affected the motor efficiency, the electric losses in the motors in all cases have been deducted from the kilowatt input in determining the mechanical efficiency of the machines. The mechanical loss of the motors and gears in each case is charged against the respective machines. The tow-line pull in all cases has been corrected to the effective pull in pounds in the direction of motion. Results are given in Table IV.

TABLE IV

Efficiency of Towing Machines

	Effective pull 1000 lb.	Effective pull 2000 lb.	Effective pull 3000 lb.
Mining Locomotive	80%	83.5%	84%
Tractor 1	68	73.3	74.8
Tractor 3	73	77.2	77.5

Expressed in another way the results are summarized in Table V.

The results of these tests are perhaps more clearly illustrated in Fig. 14, in which the inputs to the towing machines are reduced to equivalent draw-bar pulls.

The performance of the three towing machines, running light without load, is shown in Table VI. For convenience, the input to

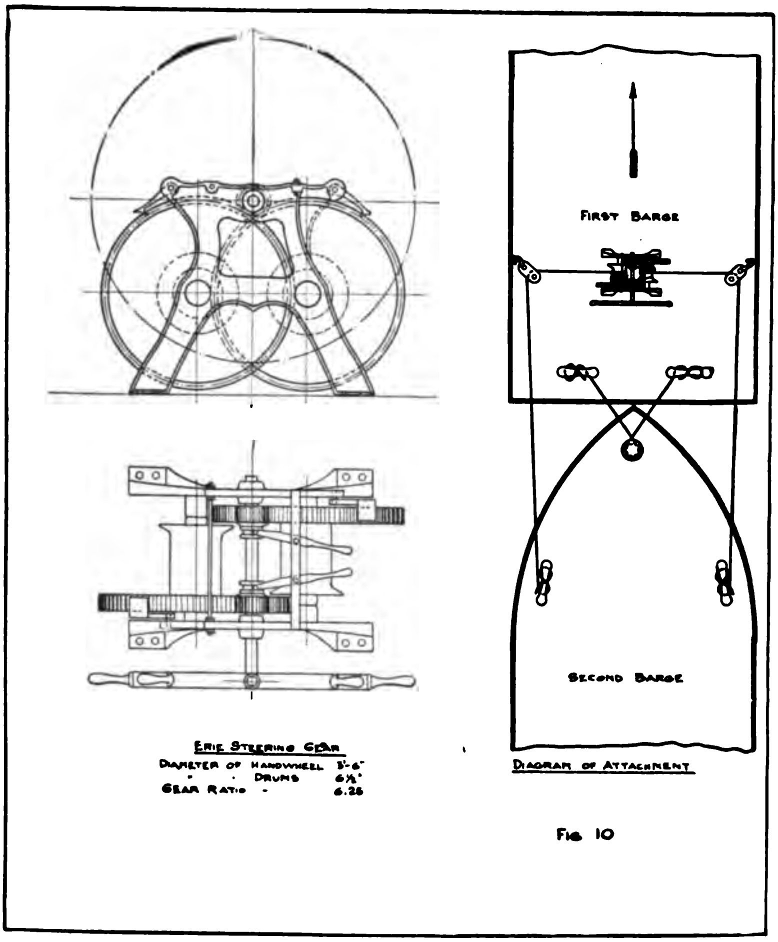
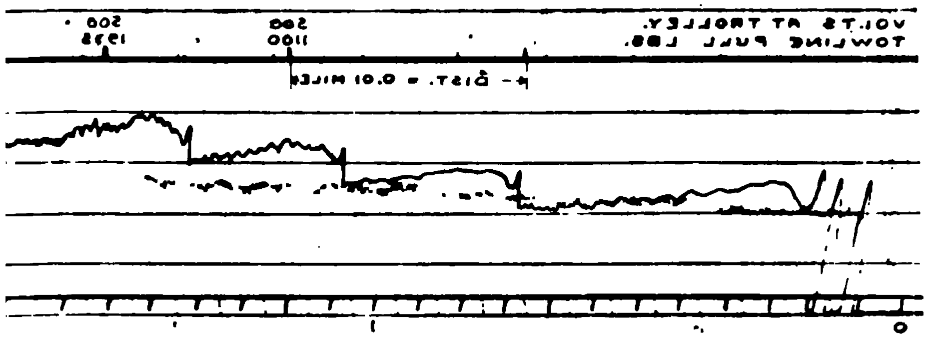
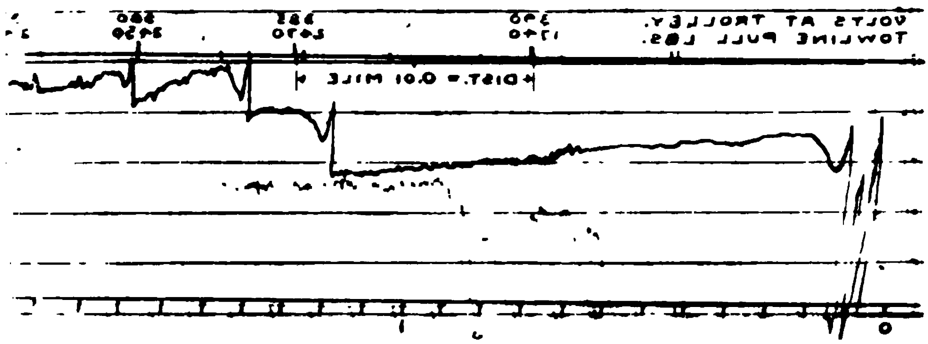
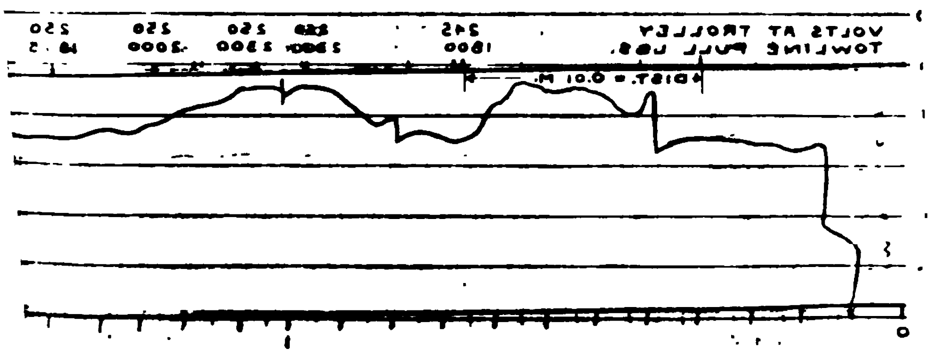


FIG. 10

the machines is expressed both in kilowatts and equivalent draw-bar pull in pounds. The values stated include all mechanical friction of motors, gears, and track, but do not include the electrical losses in the motors.


VOLTS AT TROLLEY.
TOWLINE PULL LBS.
DIST. = 0.01 MILE


VOLTS AT TROLLEY.
TOWLINE PULL LBS.
DIST. = 0.01 MILE


VOLTS AT TROLLEY
TOWLINE PULL LBS.
DIST. = 0.01 M.

TEST TRACTOR Nº 3.

BETWEEN LOCKS 4-5 DOWN.
4 BOAT TOW, WEIGHT 548 TONS.
LENGTH OF TOWLINE 200 FT.
AVE. ANGLE OF TOWLINE 15°.
AVE. VELOCITY OF WATER O.
RAIL DRY, WIND S.W. LIGHT.
RUN Nº 131, NOV. 3 1907.

KW. AT TROLLEY.

0 5 10 15 20 25 30

TEST TRACTOR Nº 1.

BETWEEN LOCKS 4-5 DOWN.
4 BOAT TOW, WEIGHT 548 TONS.
LENGTH OF TOWLINE 200 FT.
AVE. ANGLE OF TOWLINE 15°.
AVE. VELOCITY OF WATER O.
RAIL DRY, WIND N.W. LIGHT.
RUN Nº 58, OCT. 13 1907.

KW. AT TROLLEY.

0 5 10 15 20 25 30

TEST MINING LOC. Nº 15.

BETWEEN LOCKS 2-1 UP.
2 BOAT TOW, WEIGHT 274 TONS.
LENGTH OF TOWLINE 180 FT.
AVE. ANGLE OF TOWLINE 15°.
AVE. VELOCITY OF WATER 0.58 MPH.
RAIL DRY, WIND W. LIGHT.
RUN Nº 92, OCT. 22 1907.

KW. AT TROLLEY.

0 5 10 15 20 25 30

TABLE V

EQUIVALENT PULL IN POUNDS LOST IN MACHINE AND TRACK FRICTION WHEN DELIVERING

	Effective pull 1000 lb.	Effective pull 2000 lb.	Effective pull 3000 lb.
Mining Locomotive	250	400	590
Tractor 1	450	700	1000
Tractor 3	375	600	890

TABLE VI

Speed miles per hour	Mechanical Friction Running Light					
	Kilowatts			Equivalent drawbar pull pounds		
	Mining Loco.	Tractor 3	Tractor 1	Mining Loco.	Tractor 3	Tractor 1
3	0.88	.98	1.44	148	164	242
4	1.28	1.40	2.16	161	176	272
5	1.70	1.82	2.90	171	183	292
6	2.17	2.32	3.68	182	195	308
8	3.20	3.41	....	201	214	...
10	4.40	....	....	221	...	...

The results of these tests are illustrated in Fig. 13.

It will be noted that in running without load the machines preserve relatively the same relationship as they do when operating under load conditions, though the relative magnitude of the values are changed. When developing large draw-bar pulls, the mechanical losses in Tractor 3 are 50 per cent. in excess of those of the Mining Locomotive. Mechanical losses in Tractor 1 exceed those of the Mining Locomotive by from 70 to 80 per cent. Under light running conditions these excess losses are reduced to about 7 per cent. in the case of Tractor 3, though the excess remains approximately 70 per cent. for Tractor 1.

The running light losses are, in themselves, relatively unimportant, as the amount of power required is small and the amount of idle running relatively very small; but, as showing errors in design and workmanship, which extend their influence to conditions of heavy load, they are important. We shall not here enter into a theoretical discussion of the design of these Tractor machines. It is apparent that their mechanical design can be improved materially. When running light, it would be reasonable to expect that these machines, if properly designed, should effect a saving in power consumed almost

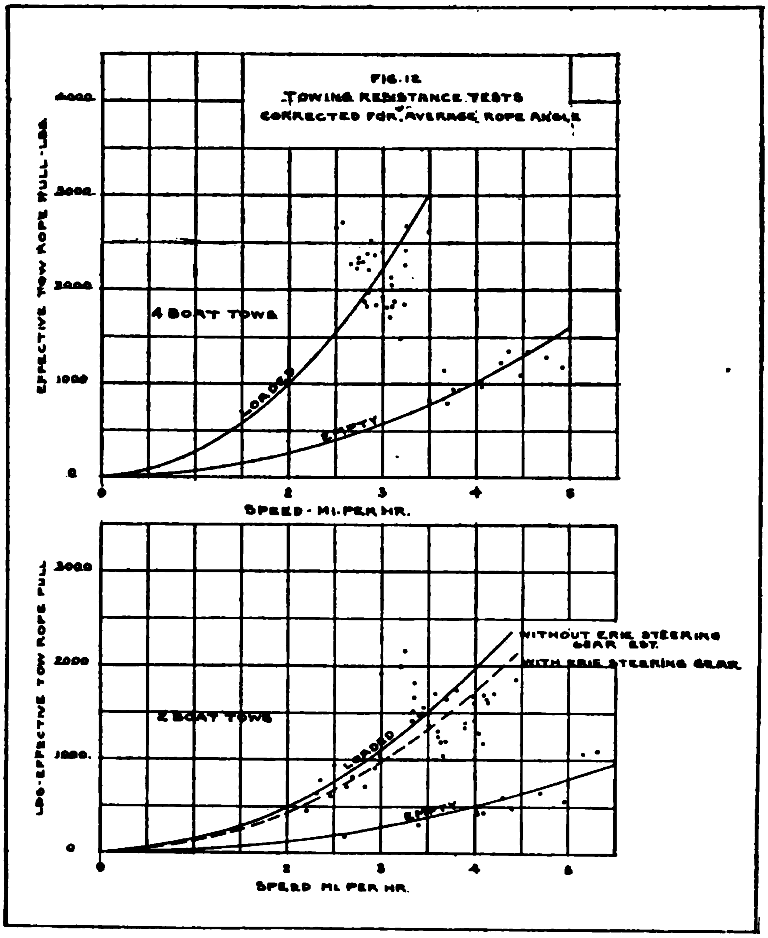


FIG. 12

proportional to their less weight as compared with the Mining Locomotive.

Under load conditions, especially as the draw-bar pull approaches the maximum of which the locomotive is capable, the latter machine, theoretically, should show the higher mechanical efficiency. This is due to the fact that when the Mining Locomotive utilizes its entire weight for traction; to obtain a similar draw-bar pull with the Tractor, the two driving wheels on top must have a pressure upon them equal to the weight of the Mining Locomotive. As the weight of the Tractor is 10,000 lb. less than that of the Mining Locomotive, a pressure of at least

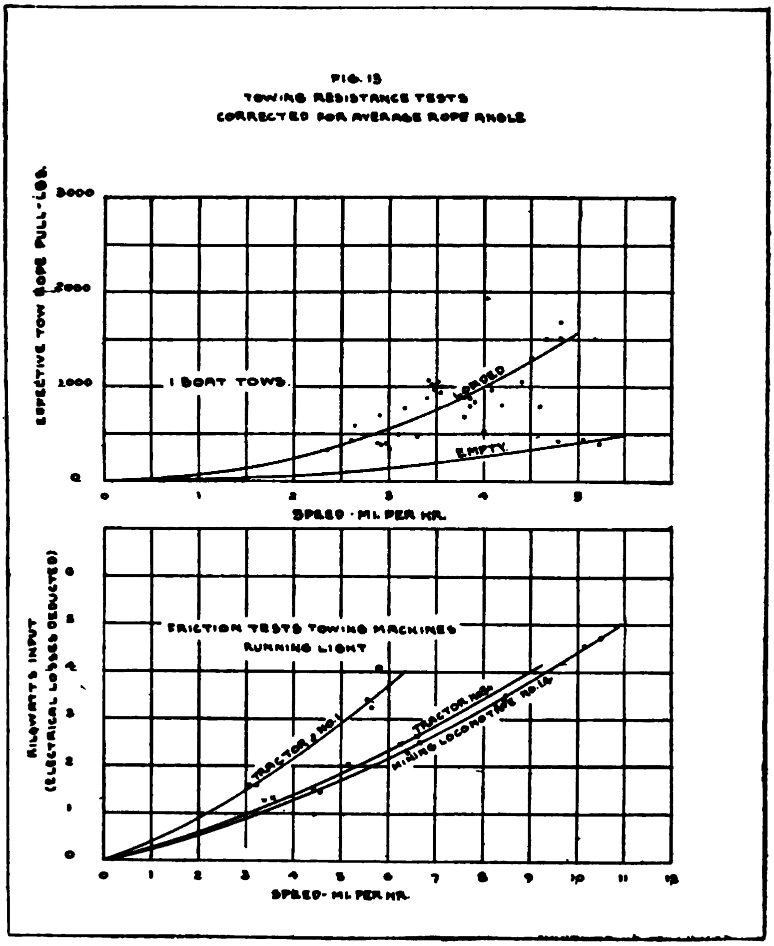


FIG. 13

10,000 lb. must be exerted on the lower or pressure wheels. It is evident, therefore, that the track and rolling friction of the Tractor must be greater than that of the Mining Locomotive by the amount of this excess pressure on the track. Considering track friction only, this excess should amount to about 60 per cent. at maximum pull. The tests of Tractor 3 show an excess of about 50 per cent. at 3,000 lb. rope pull, though the test results are not exactly comparable, as motor and gear frictions are included and are different in the two machines.

Assuming that the Tractor may be so designed that its ag-

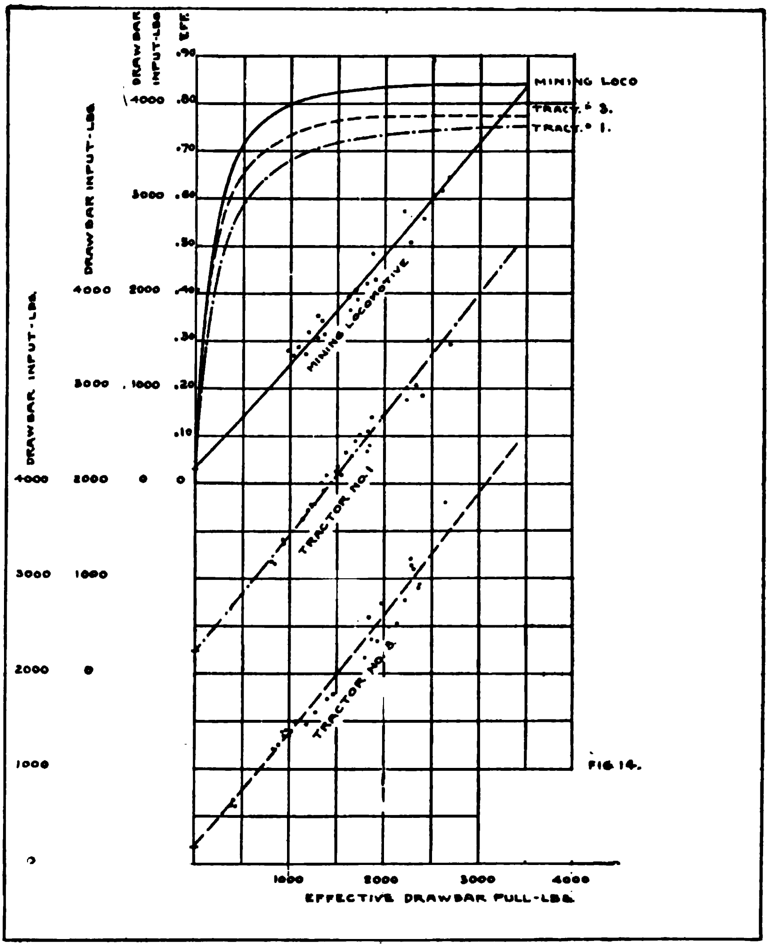


Fig. 14

gregate mechanical friction per ton of weight does not exceed that of the Mining Locomotive, it is obvious that when running light less power should be required to move the former at a given speed than is required by the latter. Assuming good mechanical design, it follows that the Tractor under light loads should be more efficient than the Mining Locomotive, and that at some load between the limits of very light load and full load, the efficiency curves of the two machines should cross. So far as comparative efficiency is concerned, therefore, great care must be taken in designing the Tractor, to minimize friction losses if it is expected to make a good showing as compared with the Mining Locomotive.

In order to assist in determining the cause of the apparently excessive friction of these Tractors, at low rope-pulls and when running light, tests were made on a wet rail to determine the relative amount of reduction in friction due to a bad rail, and other tests made pulling the Tractors with the gears and motor disconnected. The results of these tests are illustrated in Fig. 15 and show that at a speed of six miles an hour the wet rail effects a saving of about 16 per cent. in total friction, running light, and at the same speed the gear and motor friction amounted to 28 per cent. of the total. It is apparent from the tests that frictions at light loads are relatively small and at large pulls the difference is to a large extent lost as the mechanical friction approximates the theoretical amount to be expected from the pull exerted.

It would seem that the mechanical efficiency of tractors of this type might be improved by giving attention to the following facts:

1. An increase in the size of wheels would tend to decrease losses.

2. The wheel-base should be long and the " flange clearance " small.

3. The mechanical construction must be such that alignment of all bearings is preserved under all conditions of operation.

4. The point of rope attachment should be carefully selected in order to reduce flange friction to a minimum.

5. The rail surface should be as good as on ordinary railway tracks, and the construction should be such as to minimize vibration.

6. The use of guides for the pressure wheels should be avoided if practicable. If used, the vertical motion in the guides for the pressure wheels should be free.

7. The pressure wheels should have no flange.

8. Arrangements for oiling the bearings of tractors as well as of locomotives should follow railroad practice.

Speed limitations and length of tow. In hauling canal boats by mules, the speeds attained vary from 1.25 to 2 miles an hour. When the current assists, the speed exceeds these amounts; when the tow is against the current, the speed sometimes drops very low. Dynamometer tests were made, and it was deter-

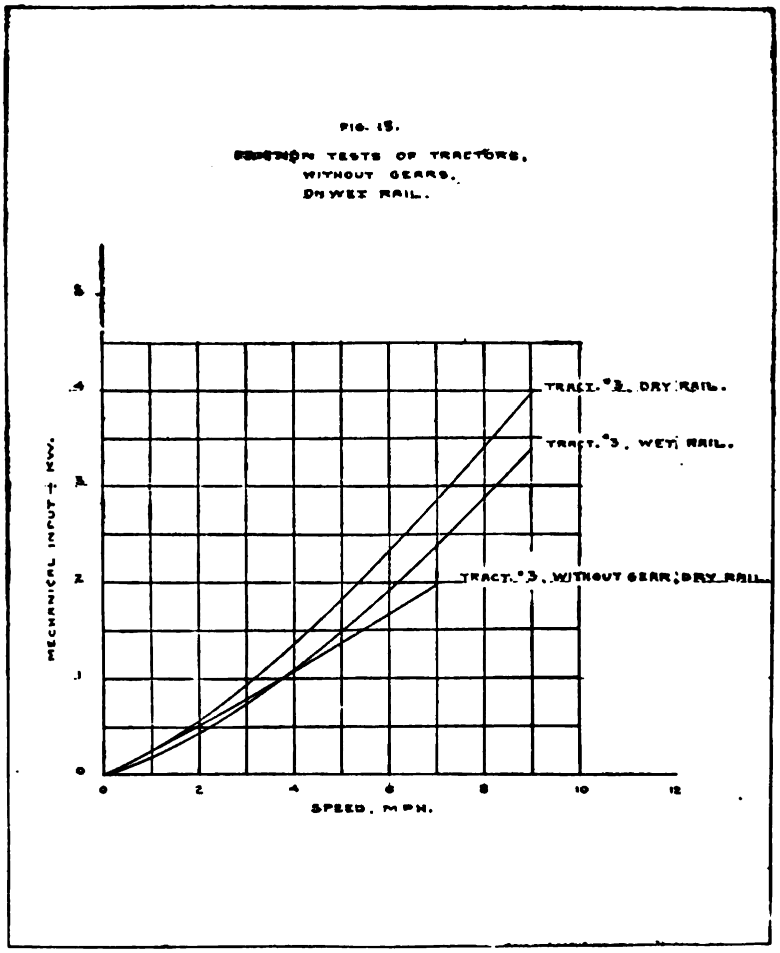


FIG. 15

mined that in starting a tow, a team of good mules could exert momentary pull approximating 800 lbs. This is maintained but momentarily.

The average speed at which a team of mules draws a one-boat tow approximates 1.75 miles an hour and does not exceed 2 miles an hour in still water. The pull required at 2 miles an hour, as determined by the tests in which the Mining Locomotive and Tractors were used, is 250 lb.; at 1.75 miles an hour it is 190 lb., and at 1.5 miles an hour it approximates 140 lb. The curves expressing the relation of pull and speed for tows of various length are shown in Fig. 16.

Tests were made to determine the practicable limits of speed when towing is done with towing machines. These limits depend upon the following:

a. Ability to steer the boats.

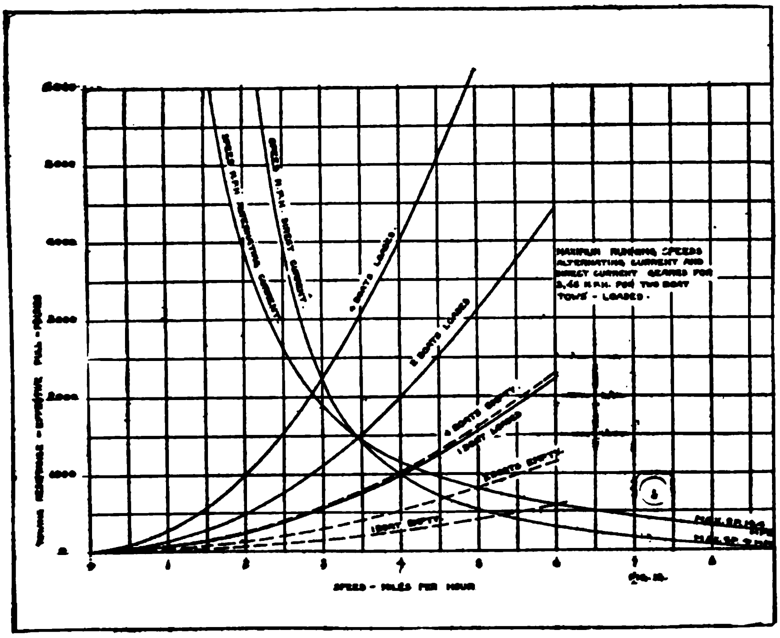


FIG. 16

b. Wash of canal banks.

c. Time required for locking.

d. Tonnage capacity and length of tow.

The selection of a best speed depends also upon the number of boats which must pass through the canal in a given time to handle its business. This will be referred to further under the heading "*Tonnage Capacity and Length of Tow*".

Ability to steer boats. Single boats, both loaded and empty, were tested at speeds slightly exceeding 5 miles an hour and no difficulty was experienced in steering them.

Two-boat tows loaded were operated at speeds up to 4.5 miles an hour. With the Erie steering gear the boats handled well at this speed, but care had to be exercised by the helmsman to keep his course true. Two-boat tows (light) were operated successfully at a speed of 5.3 miles an hour.

Four-boat tows (loaded), the first two boats being equipped with the Erie steering gear, were operated at a speed of 3.5 miles an hour. At this speed, however, it was necessary for the helmsman to exercise great care to prevent the boats yawing. Four-boat tows, empty, were operated at speeds up to 5 miles an hour, but great difficulty was experienced in steering; the drag of the rear boat's pulling the head boats against the bank in spite of anything the helmsman could do. This was especially noticeable in going around curves convex with reference to the bank upon which the tow-path was located. It was found quite impossible to start four-boat tows on such a curve.

The relations of speed and pull for tows of various lengths, loaded and unloaded, are illustrated in Fig. 16.

Our conclusions in regard to limits of speed, as fixed by conditions of practicable steering, are:

a. Single boats, loaded or empty, can be operated satisfactorily on tangents at speeds exceeding 5 miles an hour, but on the canal for satisfactory working 5 miles an hour is probably about the limit of average speed for such tows.

b. Two-boat tows are handled satisfactorily at speeds of from 3.5 to 4 miles an hour.

c. Four-boat tows loaded can be operated with a fair degree of success at speeds up to 3 miles an hour except on very sharp convex curves.

d. Four-boat tows, light, were found impracticable as tested. It is possible that improved steering gear might remedy the difficulties encountered, except that no conceivable steering-gear would make it possible to handle four-boat tows, light, in a heavy wind.

Wash of canal banks. At the higher speeds covered by the tests a tendency to cause wash of the canal banks was noted. The tests were not of sufficient duration to justify an attempt at estimating the relation of wash and speed.

At a given speed the wash is greatest in shallow and narrow sections of the canal. To a certain extent in these sections the speed is automatically regulated; the resistance to the passage of the boat being increased and this resistance immediately reacting upon the series motor used in our tests.

The speed of towing should be under the control of the operator, and to obtain best results the motor used should be capable of operating at any desired speed within the predetermined maximum limits. With equipment of this character, the speed can be regulated on those sections where the wash might otherwise be injurious.

Time required for locking. Tests were made to determine the time required in locking one, two and four boats and to see if the time could be reduced in any way. The following is a typical locking for two- or four-boat tows under test conditions.

TABLE VII
LOCKING TESTS

	Lift 8 ft. Lock No. 4 4 boats		Lift 8 ft. Lock No. 5 2 boats
	First 2 boats Erie steering-gear, minutes	Second 2 boats No gear minutes	First 2 boats Erie gear, minutes
Tow-line let go	00.00	00.00	00.00
First boat entered lock	1.75	....	....
First boat tied in lock	1.25	3.00	2.00
Second boat tied in lock	1.75	3.75	3.50
Upper gate closed (lock emptied)	0.75	.25	1.00
Lower gate opened	2.00	3.50	3.00
First boat started out	.00	.25	.00
Second boat started out	1.75	.25	0.75
First boat out	0.25	1.25	0.25
Steering-gear adjusted	2.00	1.00*	1.50
Started pulling both boats	.00	1.25	....
Both boats out of lock	0.50	0.50	0.25
	12.00	15.00	12.25
Lower gate shut	.50	....	1.00
Upper gate opened	2.00	....	1.75
	2.50		2.75

* Boats tied together only, no steering-gear.

SUMMARY

First two boats	12.00	minutes
Refilling lock	2.50	"
Second two boats	15.00	"
Total four-boat tow	29.50	

The foregoing figures represent average results obtained in tests. During these tests the men handling the boats were working at a speed which they could not be expected to attain in normal service and, therefore, we have based upon the test results estimates of the average time of locking to be expected in ordinary working.

The actual time, as determined by test and our estimate for average conditions, (the latter of which is used in subsequent calculations) is given below:

TABLE VIII

Time locking two-boat locks	Observed test time	Estimated average time
Time locking four boats	29.5 min.	35 min.
Time locking two boats	12.0 "	15 "
Time locking one boat	8.0 "	10 "

In four-boat locks, with the first two boats and the last two boats equipped with Erie steering-gear, it would not be necessary to disconnect the steering-gear and the time of locking would not greatly exceed that for two boats. An estimate of 20 minutes we think is conservative.

No actual tests of the single-boat locks on the Delaware canal were made using canal boats, but during a trip of inspection the time of all lockings of the launch used were taken, and from these observations the time of locking for canal boats was estimated as follows:

TABLE IX

Coasting into lock, tests 4 and 5	2.75	minutes
Upper gate up (average on trip)	.50	"
Lower gate opened (average on trip)	1.75	"
Boat out, average of tests	1.50	"
	6.50	
Time refilling lock and opening gate	2.75	"
Add for second boat	6.50	"
Adjust steering gear	2.00	"
Two boat tow, total time	17.75	"
Estimated average time	21.00	"

The following table gives the estimated average time for locking with tows of different lengths and with locks of different size as used in our calculations.

TABLE X

	1 boat lock	2 boat lock	4 boat lock
Time locking four boats	45	35	20
Time locking two boats	21	15	12
Time locking one boat	8	10	11

The following table gives the estimated time spent in locking from Coalport to Bristol for tows of different lengths based upon the above estimates of time required per lock. (There are 1 four-boat locks and 47 two-boat locks on the Lehigh Canal and 10 two-boat locks and 12 one-boat locks on the Delaware Canal.)

TABLE XI

Four-boat tows, hours one way	42.6 hours
Two-boat tows, hours one way	18.7 "
One-boat tows, hours one way	11.3 "

Conclusions. The following is a tabulation of the speeds recommended for tows varying from one to four boats, loaded and empty, assuming, (*a*), that direct-current series motors are employed, and, (*b*), that single-phase alternating-current motors of the compensated type be used.

TABLE XII
MAXIMUM SPEED BETWEEN LOCKS

	Direct current	Alternating current
Four boats loaded	3.00	2.88
Four boats empty	4.00	4.20
Two boats loaded	3.45	3.45
Two boats empty	4.60	5.00
One boat loaded	4.00	4.20
One boat empty	5.30	6.00

Our conclusions in respect to speeds are based upon the observed facts as regards ability to steer boats, the wash of canal banks, the relative time required in locking, and between locks and the tonnage capacity of the canal as affected by the length of tow.

The speeds recommended for direct-current and alternating-current motor equipment respectively, differ by reason of the different speed characteristics of the motors of these respective types. The speed characteristic of the direct-current motor used is that of the series motor on Tractor 1 as used during the tests. The speed characteristics of the alternating-current

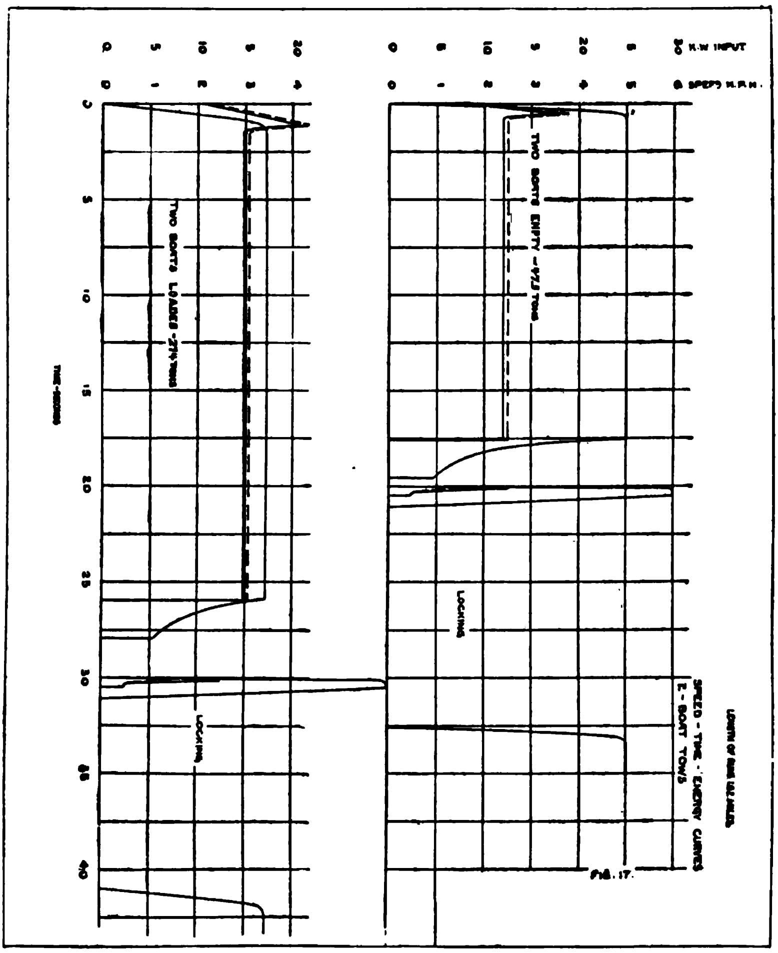


FIG. 17

motor are those of a typical series, compensated, 25-cycle motor. In Fig. 16 the speed curves of these two motors are plotted upon the assumption that the gear-ratios selected are such as will give the same speed for the two contrasted equipments in pulling a tow of two loaded boats, the length of tow being that which, from a purely physical consideration of the problem, appears best.

We have assumed the same speed characteristics of electrical equipment in comparing the mining locomotive with the tractors. The motors with which these respective machines were equipped during tests did not have identical speed characteristics; but there is no reason why they could not be so designed, and the assumption simplifies the general comparison with two types of towing machines.

Tonnage capacity and length of tow. As the length of tow limits the practicable running speed and determines the time consumed in locking, the length of the tow directly affects the tonange capacity of the canal. The maximum running speeds described above, and shown graphically in Fig. 16, give average running speeds which were determined from speed-time curves as shown in Fig. 17. The following table gives the average time required for four-, two-, and one-boat tows to make the round trip from Coalport to Bristol loaded and return empty.

TABLE XIII

TIME IN TRANSIT OVER ENTIRE CANAL—106.2 MILES, WITH EXISTING LOCKS

System of Operations	Direct current			Alternating current		
Number of boats in tow	Four boats	Two boats	One boat	Four boats	Two boats	One boat
Time locking, down	42.6	18.7	11.3	42.6	18.7	11.3
Time between locks, down	34.8	30.2	25.8	36.3	30.2	24.6
Time locking, up	42.6	18.7	11.3	42.6	18.7	11.3
Time between locks, up	25.8	22.5	19.4	24.9	20.6	17.1
Add 10% contingencies	14.2	8.9	7.2	14.6	8.8	6.7
Total in transit, round trip	160.0	99.0	75.0	161.0	97.0	71.0

In order to handle a definite amount of freight, it is evident that a definite number of boats will have to pass through the canal, whether they are operated in four-, two-, or one-boat tows. The number of boats required for this service, however, will be proportional to the time required for a round trip. With a fixed amount of freight to be handled, therefore, it is evident that fewer boats will be required with one-boat tows on account of the higher average speed. The number of towing machines required for the service is proportional to the round trips required and the time for the round trip.

Table XIV shows the ratio of boats required and towing machines required for a definite traffic with tows of different lengths and locks as now existing on the canal:

TABLE XIV

RATIO BOATS AND TOWING MACHINES REQUIRED

	Direct current			Alternating current		
	Four-boat tows	Two-boat tows	One-boat tows	Four-boat tows	Two-boat tows	One-boat tows
Boats required...	2.25	1.39	1.05	2.27	1.36	1.00
Machines required	0.56	0.70	1.05	0.57	0.68	1.00

The ultimate capacity of the canal is limited by the time required in locking. Table XV expresses the ratio of the ultimate capacities with four-, two-, and one-boat tows. Since boats are moving in both directions, the interval between tows is double the maximum time required in passing through that lock on the canal which requires the maximum time for the towing unit employed. We have prepared this table :

a. On the basis of locks as now existing,

b. All one-boat locks changed to two-boat locks.

c. All locks changed to four-boat locks.

TABLE XV

MAXIMUM TRAFFIC CAPACITY

	Four-boat tows	Two-boat tows	One-boat tows
Existing locks.			
Minimum interval between tows........	90 min.	42 min.	22 min.
Ratio maximum capacity..............	0.98	1.05	1.00
One, changed to two-boat locks.			
Minimum interval between tows........	70 min.	30 min.	22 min.
Ratio maximum capacity..............	1.25	1.47	1.00
All four-boat locks.			
Minimum interval between tows........	40 min.	24 min.	22 min.
Ratio maximum capacity..............	2.20	1 83	1.00

On the Delaware Canal, where there are now 12 single locks, there is practically no gain in capacity by increasing the length of the tow. On the Lehigh Canal the capacity is increased nearly 50 per cent. by using two-boat tows, but only 25 per cent. with four-boat tows. The conversion of all the locks on both canals to four-boat locks would approximately double the capacity.

Power required. Speed-time curves have been constructed for both the mining locomotive and the tractor for the towing speeds selected as most practicable and described under the caption " *Conclusions* " for both single-phase alternating-current motors and direct-current motors. The general character of these curves is illustrated in Fig. 17 for a two-boat tow over an

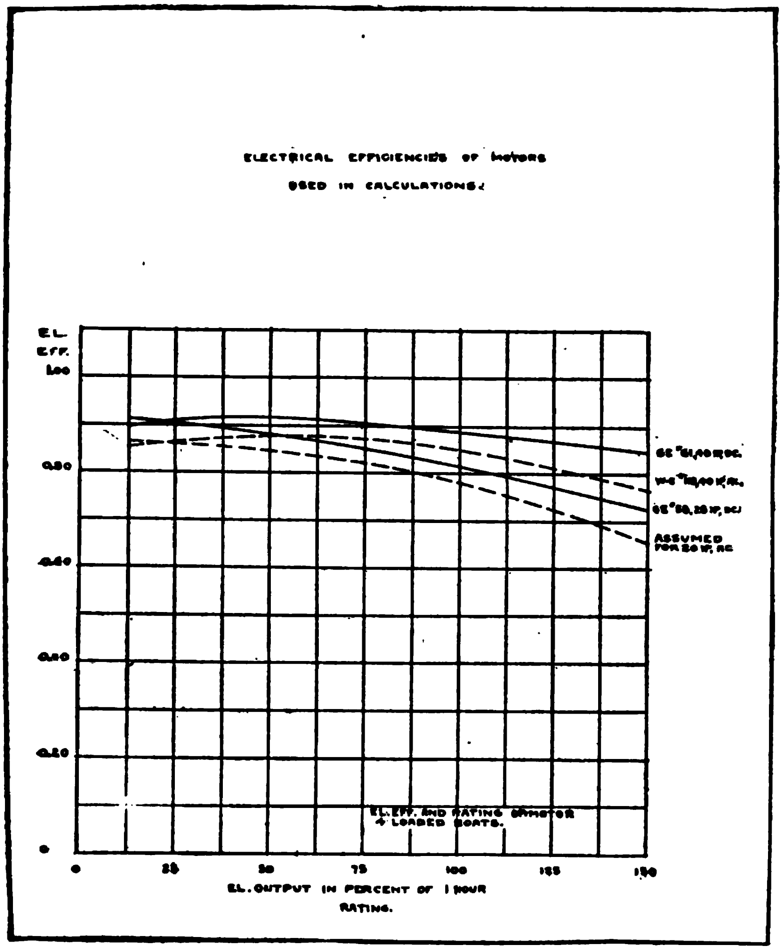


FIG 18

average run of 1.516 miles. The towing machines as tested were not equipped with motors suitably geared for the speeds desired. We have therefore, assumed these towing machines to be equipped with motors of suitable size and speed and possessing the same efficiencies at their rated loads as the motors furnished by the manufacturers. The motor efficiencies are shown in Fig. 18. These efficiencies have been applied to the mechanical efficiencies of the towing machines, as shown in Fig. 14. We have so applied these efficiencies that the input for a four-boat tow

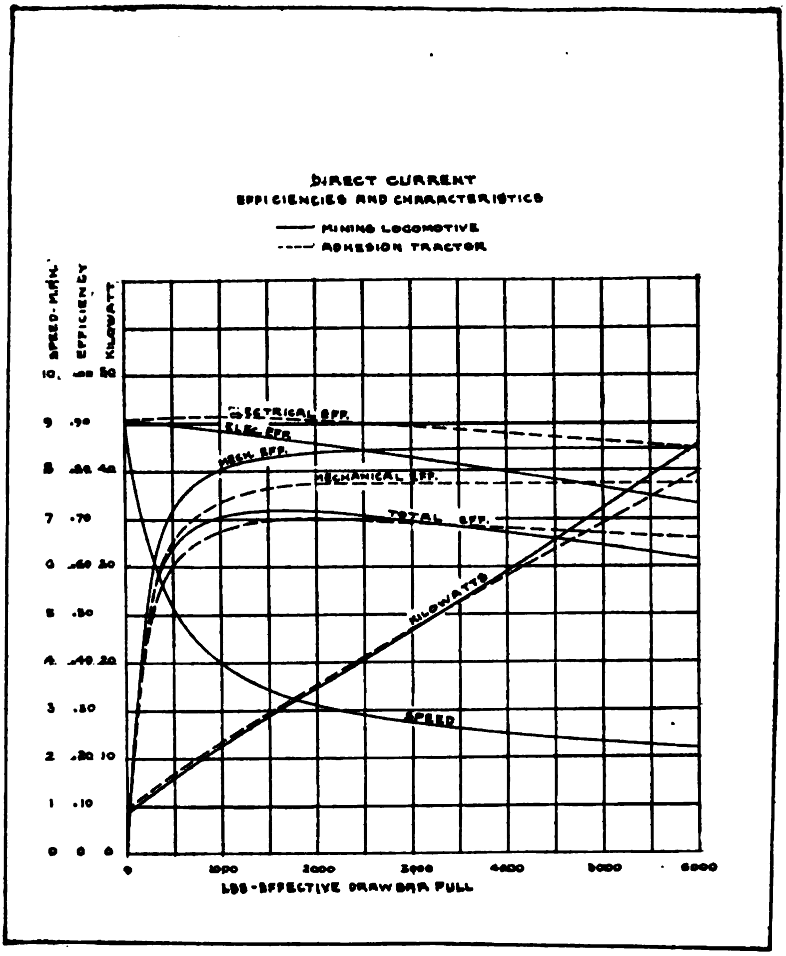


FIG. 19

(loaded) at the speed selected, will be 75 per cent. of the one-hour rating of the motor. The speed selected for both direct-current and alternating-current also corresponds to the speed recommended for two-boat tows. As already pointed out, this gives approximately the desired speeds for other tows.

Direct-current motors. The total efficiencies, kilowatt input at trolley, and speeds for the mining locomotive and tractor are given below. The efficiencies and inputs include all mechanical and electrical losses:

TABLE XVI

	Speed mi. per hr.	Mining Locomotive		Tractor	
		Per cent. efficiencies	Input kilowatts	Per cent. efficiencies	Input kilowatts
Effective pull,					
At 1000 lb.	4.0	70.2	11.3	67.2	11.8
At 2000 lb.	3.1	71.6	17.3	70.0	17.7
At 3000 lb.	2.7	69.5	23.3	69.0	23.5

It will be noticed that there is comparatively little difference in the efficiencies of the two machines tested, notwithstanding the fact that, as previously stated, the mechanical losses of the tractor materially exceed those of the mining locomotive. This is due to the fact that the electrical losses of the two small motors used on the mining locomotive exceed the electrical losses in the single large motor used on the tractor; assuming in both cases that the motors are geared to obtain the speed which we have selected.

Improvements in design would make it possible for the mining locomotive to retain a larger part of its advantage, due to its less mechanical friction.

The relative efficiencies and characteristics of the two machines are illustrated in Fig. 19.

Alternating-current motor. By a similar process, the characteristic curves for single-phase, alternating-current operation have been deduced. In providing motors for the mining locomotive, we have assumed the same ratios between the efficiencies of two- and one-motor equipments as existed in case of direct-current. The following table shows the comparison of the two machines, including all mechanical and electrical losses:

TABLE XVII

	Speed mi. per hr.	Mining Locomotive		Tractor	
		Per cent. efficiencies	Input kilowatts	Per cent. efficiencies	Input kilowatts
Effective pull,					
At 1000 lb.	4.3	66.8	13.0	64.5	13.4
At 2000 lb.	2.9	68.4	17.0	67.0	17.3
At 3000 lb.	2.3	67.2	21.2	66.5	21.5

The respective characteristics of the two machines are also shown in Fig. 20.

The average efficiency of the mining locomotive is about 1.5 per cent. higher than that of the tractor both with alternating-

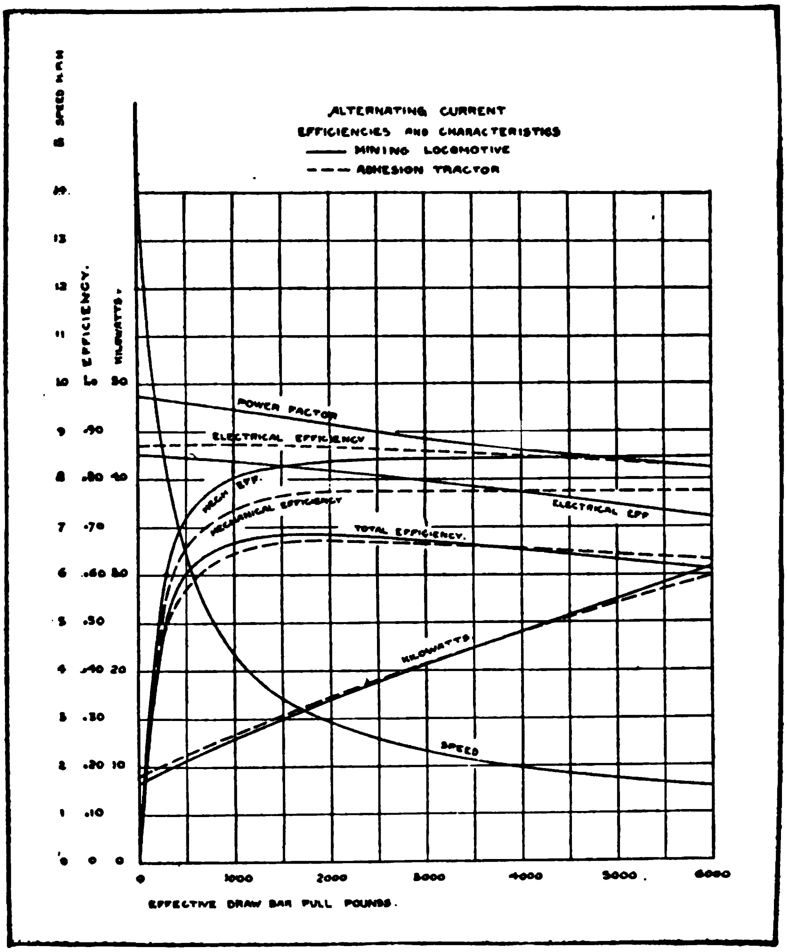


Fig. 20

current and direct-current equipment and the average efficiency at the trolley is about 2.8 per cent. higher with direct-current than with alternating-current.

In this case, as in the case of direct-current equipment, it is evident that the difference in efficiency of the mining locomotive and the tractor, and of alternating-current and direct-current equipment, are relatively unimportant as compared with other factors upon which the choice of one or the other as a system of electrical haulage must depend.

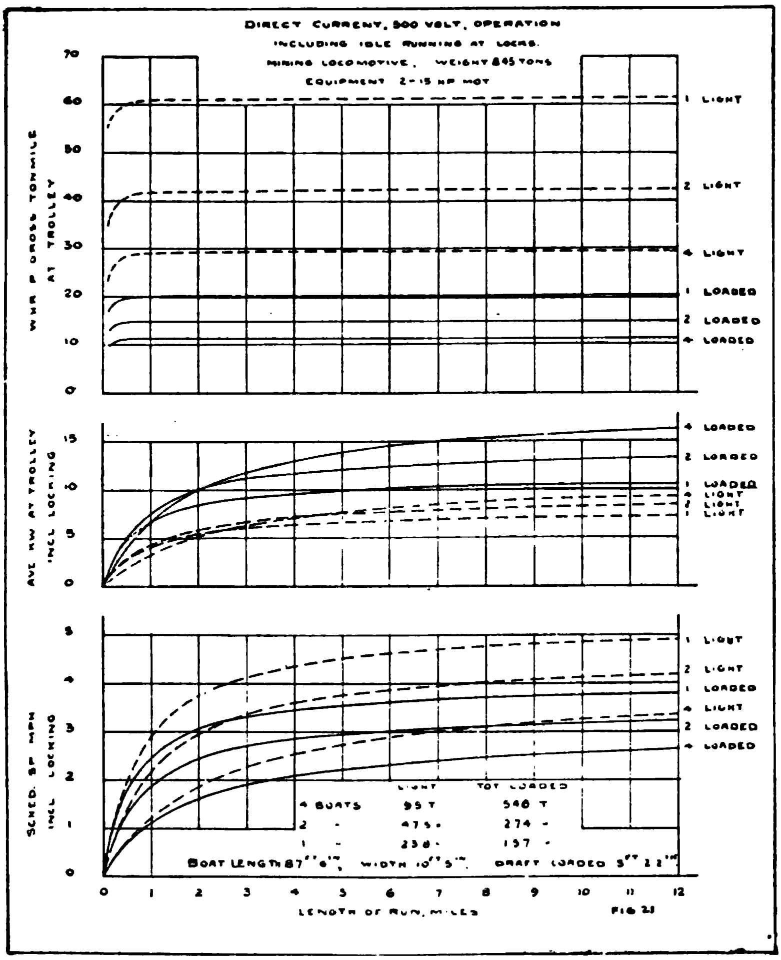


Fig. 21

Characteristic curves showing the average speed including locking for runs of different length, the average power required at the trolley, and the watt-hour per ton-mile for four-, two-, and one-boat tows for the mining locomotive and the tractor and for both alternating current and direct current are shown in Fig. 21, 22, 23, and 24.

The average length of run for the entire canal is 1.52 miles, and from calculations we have made it appears entirely practic-

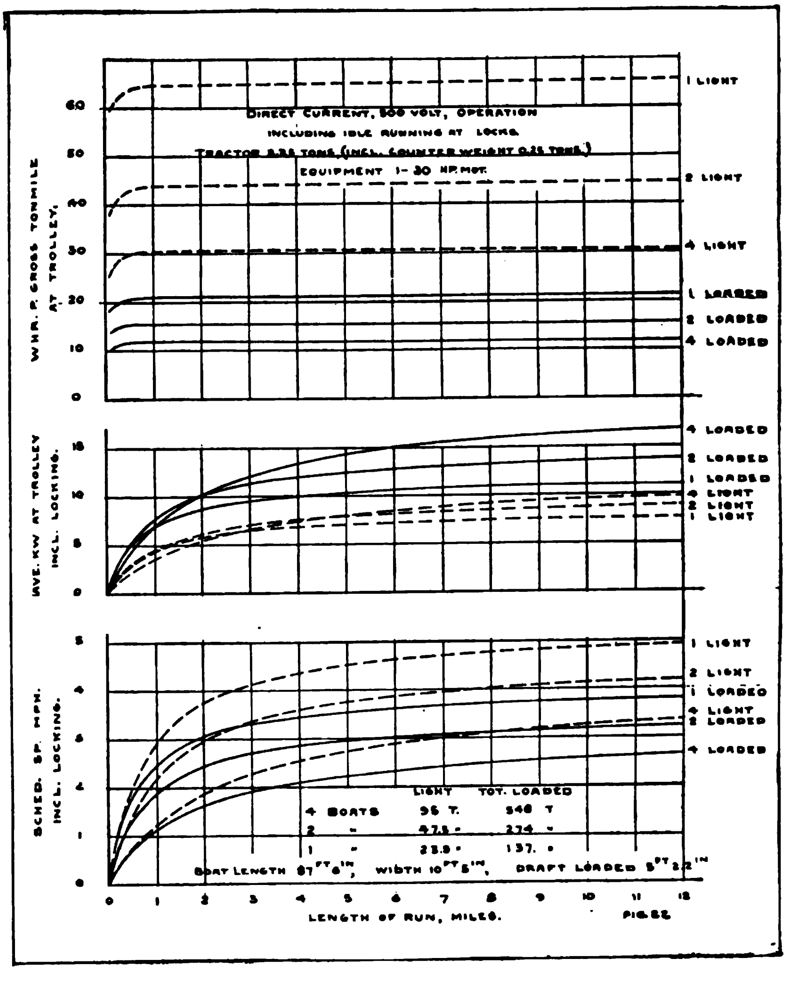


Fig. 22

able to use a run of this length as typical for the entire canal. Table XVIII shows the more important points brought out by these curves, on the basis that the locks are enlarged as necessary to accommodate two-boat tows.

TABLE XVIII

SPEED, KILOWATT INPUT, AND WATT-HOURS PER TON-MILE. AVERAGE RUN 1.52 MILES —TWO-BOAT LOCKS. TIME LOCKING: 4 BOATS 35 MIN.; 2 BOATS 15 MIN., 1 BOAT 10 MIN.

	Speed		Mining Locomotive		Tractor	
	Maximum speed mi. per hr.	Average speed including locking mi. per hr.	Average input at trolley kilowatts	Watt-hours per ton-mile	Average input at trolley kilowatts	Watt-hours per ton-mile
Direct current.						
4 boats loaded....	3.00	1.40	8.7	11.3	8.8	12.0
4 boats empty....	4.00	1.60	4.3	20.2	4.6	30.3
2 boats loaded....	3.45	2.22	9.1	14.8	9.3	15.5
2 boats empty....	4.57	2.65	5.2	41.9	5.4	44.0
1 boat loaded.....	4.00	2.81	7.7	20.0	8.0	21.0
1 boat empty.....	5.30	3.42	4.9	61.0	5.2	64.5
Alternating current						
4 boats loaded....	2.88	1.37	8.1	11.0	8.2	11.1
4 boats empty....	4.13	1.59	5.0	33.5	5.3	34.8
2 boats loaded....	3.45	2.22	9.6	15.5	9.9	16.0
2 boats empty....	4.98	2.78	6.6	50.8	6.8	53.0
1 boat loaded.....	4.19	2.90	9.0	22.6	9.4	23.3
1 boat empty.....	6.00	3.67	6.7	77.0	6.9	80.8

TABLE XIX

WATT HOURS PER TON MILE AT POWER HOUSE (AVERAGE FREIGHT HAUL 55.6 MILES)

Ton—2000 lb.	Direct Current		Alternating Current	
	Mining locomotive	Tractor	Mining locomotive	Tractor
Watt-hours per total ton-mile				
Four-boat tows..................	24.6	24.8	22.6	23.0
Two-boat tows..................	30.9	32.5	32.5	33.8
One-boat tows..................	42.8	45.3	48.3	50.2
Watt-hours per freight ton-mile				
Four-boat tows..................	33.9	37.2	32.5	33.1
Two-boat tows..................	44.5	49.7	46.7	48.6
One-boat tows..................	61.5	69.0	69.5	72.2

For the conditions existing on the Lehigh and Delaware Canals, it is estimated that the efficiency of a system of electric power transmission and conversion supplying direct current to motors will approximate 70 per cent. from bus-bars at power

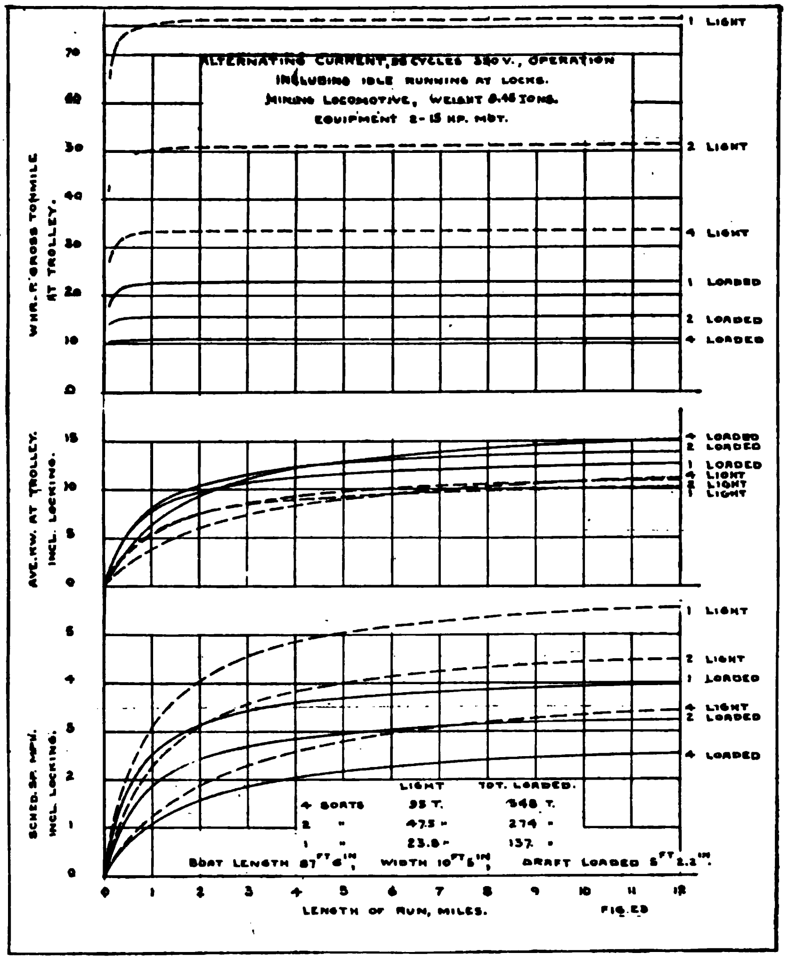


FIG. 28

house to motor terminals. If alternating-current motors be used the calculated corresponding efficiency is 75 per cent. Based upon these efficiencies and the traffic conditions as existing on the Lehigh and Delaware canals, the watt-hours required at the power house per total ton-mile and per ton-mile of freight handled are given in Table XIX.

It should be noted that the calculated power for canal transportation, as set forth in the above table, applies only to the

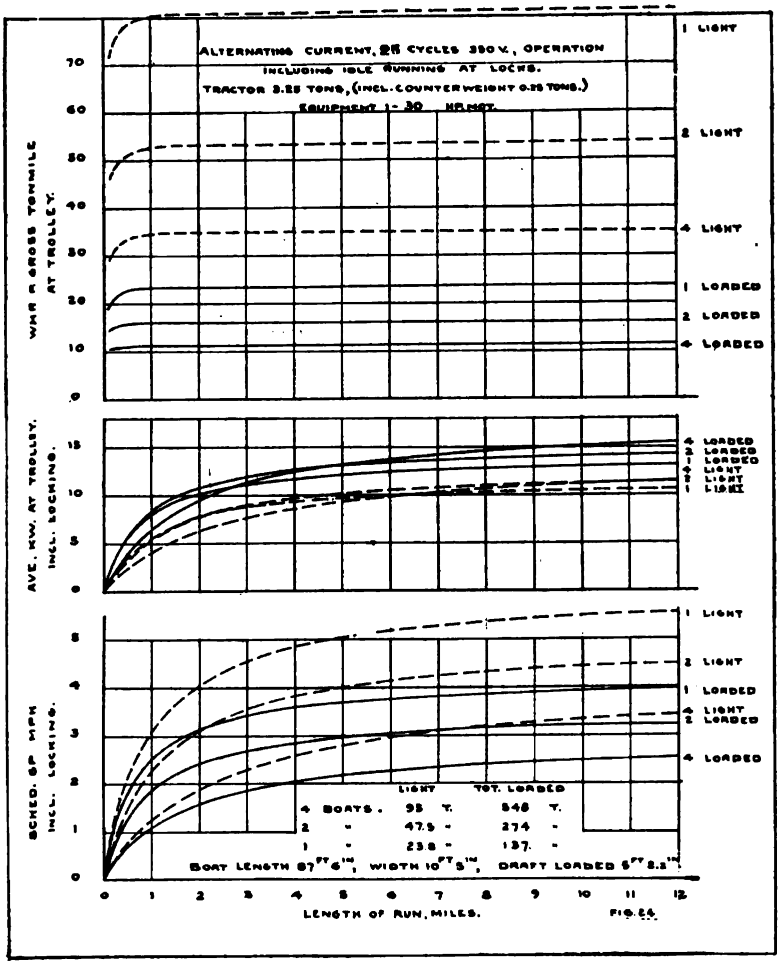


FIG. 24

especial conditions imposed by the physical limitations of these particular canals and by the speeds for loaded and for light boats which we have selected as most suitable for their operation.

Appendix.

The tests conducted on the Lehigh Canal were for the purpose of determining the practicable towing speeds and the power re-

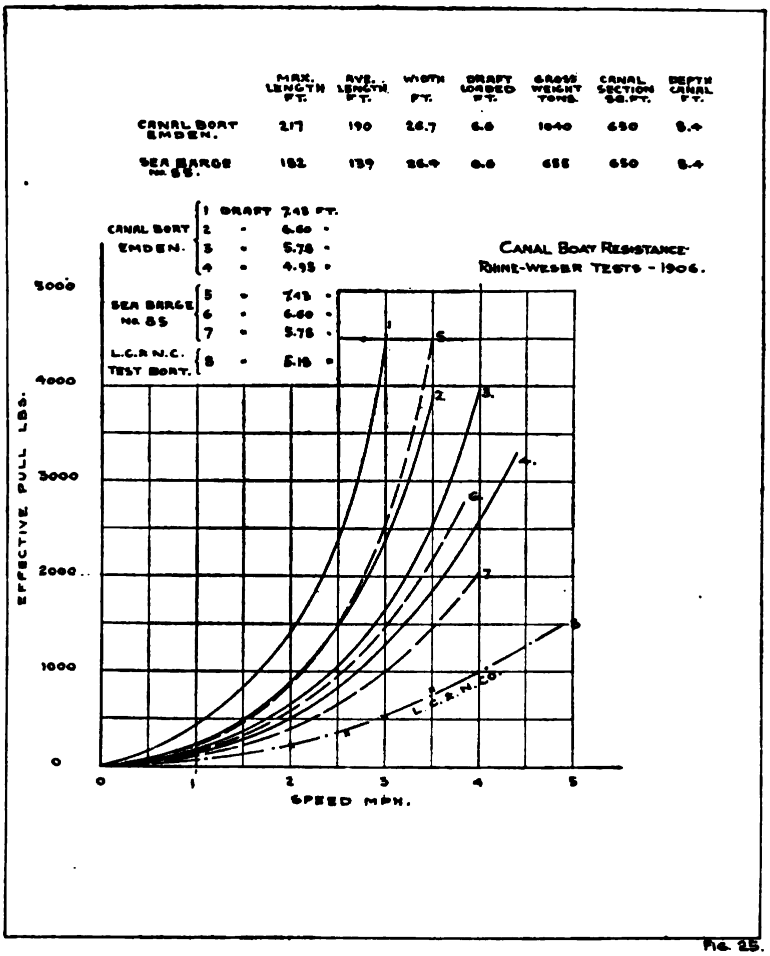


Fig. 25

quired to pull a boat of the type used on that canal. A general investigation of canal-boat resistance was not attempted. It is of interest, however, to compare the results with those obtained in the very complete tests made by Sympher, Thiele, and Block on the Rhine-Weser Canal in 1906. In Fig. 25 we have reproduced the results of these tests, as well as the results obtained on the Lehigh Canal.

The Rhine-Weser curves indicate that the clearance between the bottom of the boat and the bottom of the canal is most important as affecting canal boat resistance. In Fig. 26 we have plotted the results of one of the series of Rhine-Weser

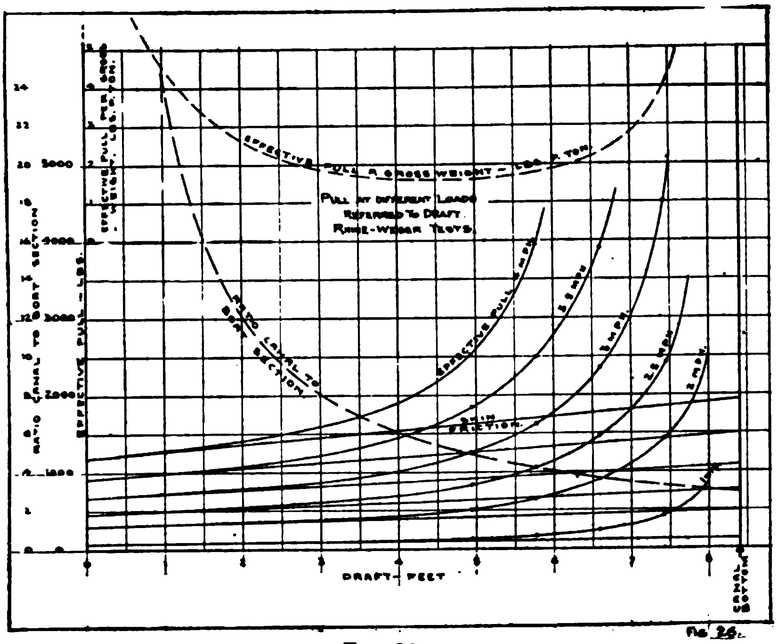


Fig. 26

tests in terms of draft and have deduced the skin friction from the Lehigh tests. This gives a point which permits the extension of the curve to zero draft with approximate accuracy. It will be noted that with a constant speed the resistance bears but slight relationship to the ratio of canal to boat cross-section, but is affected to a much greater extent by the clearance between the boat and the bottom of the canal.

In Fig. 27 we have plotted the difference between the total friction and the skin friction in terms of resistance per square foot of bottom surface as related to the clearance below the bottom of the boat. The points shown are from two tests, the boats in each case having the same cross section but different lengths and differently shaped bow and stern. The results show a fairly close agreement in the unit of resistance as referred to the bottom clearance. It is unfortunate that the tests did not include boats of the same draft but with different bottom clearances, but the data obtained indicates the importance of the clearance below the bottom of the boat, a point that until recently has been generally overlooked in canal work.

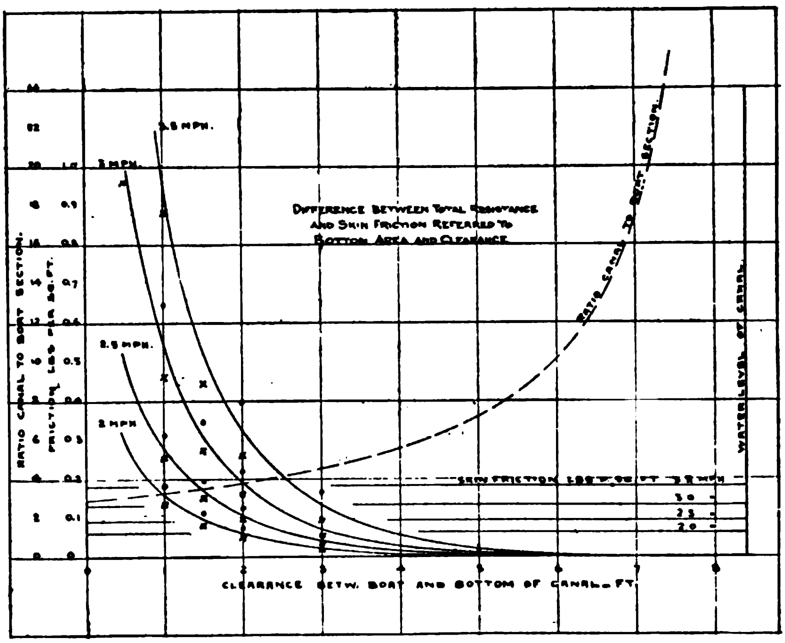


Fig. 27

An interesting point brought out by this method of plotting the test results is that the sea barge No. 85, with the same cross-section as the canal boat Emden, but with a length of 182 ft. instead of 217 ft., shows the smaller unit resistance as referred to the bottom clearance. The increase in unit resistance in case of the longer boat is probably due to the reduction in bottom clearance on account of the settling of the boat and the angle assumed by it relative to the general surface of the water under speed conditions. If the angle is the same in both cases, the stern of the longer boat will be brought closer to the bottom than will that of the shorter boat, with the result that the effective bottom clearance will be reduced. It will be noted that this effect is most marked at higher speeds, as we should expect to be the case.

As a matter of interest, the unit values in Fig. 27 have been applied to the boat as tested on the Lehigh Canal, the average bottom clearance being estimated at 1.57 feet, and the ratio of canal section 8 to 1 as compared with 3.6 to 1 as existed with this clearance in the Rhine-Weser tests. The resulting points are shown in Fig. 25 and closely agree with the test results.

In Fig. 28 we have plotted the total pull per ton required

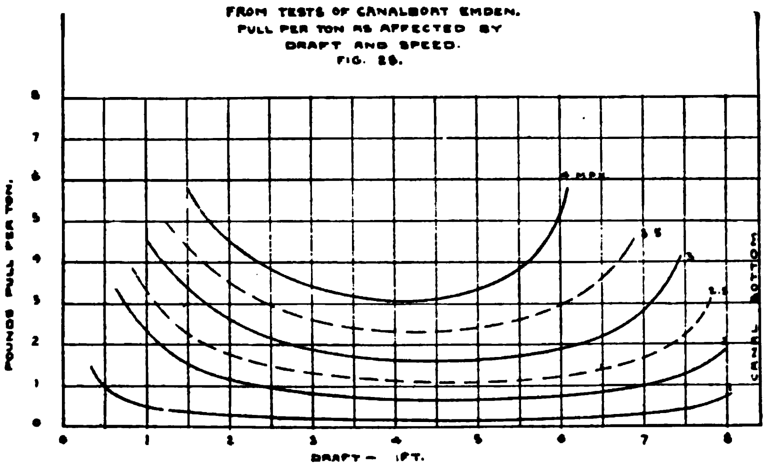


FIG. 28.

at various uniform speeds and with different drafts. These curves show that for a given speed there is a load at which the pull required per ton is a minimum, and that the pull required per ton increases rapidly as the clearance beneath the boat is diminished beyond a certain point. A relatively small clearance is permissible at low speeds but at the higher speeds which can be attained in mechanical towing the bottom clearance must be carefully considered.

The important fact brought out by the curves plotted in Fig. 28, is that the power required to tow a canal boat at a given speed is a minimum per ton of gross weight when the draft is approximately one-half the depth of the canal. The curve of resistance at a given speed with different drafts closely approximates a hyperbola; and a hyperbola, representing the resistance, divided by a straight line, representing the tonnage as referred to draft, gives a minimum at one-half the depth of the canal. The same law probably applies to the width of the boat as compared with the width of the canal. With data of similar character and with known cost of power, crews, and canal-boat maintenance, the most economical type of boat and speed for a given canal can be determined.

Discussion on "Notes on Electric Haulage of Canal Boats." New York, March 13, 1908.

Richard Lamb: This seems an opportune time to discuss this subject, for the public at large seems to be giving considerable attention to the subject of the waterways. The government officials at Washington are suggesting that there be legislative enactments in the matter of the water powers, so that these powers can be conserved for future use. Undoubtedly, in many cases these water powers will be used to propel boats, especially if such work as has been illustrated here to-night is carried to completion.

I do not agree that efficiency can, to a great extent, be disregarded. As engineer for the company that contracted to tow canal boats on the New York State canals, I had occasion to investigate, in a practical way, the subject of canal-boat towing. The results of the tests made on the Erie canal at Tonawanda, N. Y., showed that the cost for towing a boat from Albany to Buffalo by mules, steam propellers, and by electric motor were, respectively, $42.24, $17.60, and $15.32, with relative speeds of 1.3 miles, 3 miles, and 3.6 miles per hour. In order to compete with the principal motive power now in use, the mule, great care should, therefore, be taken to obtain the most efficient motor, from both mechanical and electrical standpoints.

In this country attempts have been made to utilize the towpath for a railroad bed, and to tow the boats by standard locomotives. These tests proved unsatisfactory, because of the necessary slow speed at which the boats had to be towed. The dead load and the fuel consumption of a locomotive going only three miles an hour made the standard locomotive very inefficient for this purpose. A low rate of speed is the governing factor in canal-boat towing. This attribute is inherent, because of the limited distance between the bottom of the boat and the bottom of the canal.

It sounds like a paradox to say that when a canal boat is pulled at its maximum speed, it stands still. The bottom of an Erie canal-boat is nearly flat and is 17.5 ft. wide. The distance from the bottom of a loaded boat to the bottom of the canal is one foot. Conceive of an area equal to the width of boat and the distance from the bottom of the boat to the bottom of the canal as being an orifice through which water must flow. The area is 17.5 sq. ft. When the boat is standing still there are 12,827 gallons of water under her. At 6 miles per hour, 1166 gallons per second would have to pass through 17.5 sq. ft. of sectional area, if the boat remained as it was; but as a matter of fact the boat settles as the speed increases, and therefore the sectional area under the boat decreases, making it impossible for so large a quantity of water to pass under the boat in so limited a time. Hence the water passes to easier channels, to both sides of the boat, until there is no water under the boat and it stops. Therefore, as soon as the maximum speed is reached, the boat stops.

An intumescence of the water at least one-foot high forms about a loaded Erie canal-boat when going three miles an hour. This water, not being able to pass under the boat, passes to either side, making a wave. At four miles an hour, a loaded canal boat on the Erie canal generates dead water under the stern so that it is practically impossible to steer her, and the curves on the canal make navigation at this speed difficult and dangerous. I consider that after equating for first cost and maintenance of canal and electric towing plant, and the maximum carrying capacity of boats, that a speed of three miles an hour is the greatest that should be sought. The wash of the canal bank, caused by the waves generated by a boat going more than three miles an hour is no inconsiderable factor in maintaining the canal.

In the paper under discussion all the records of the draw-bar pulls are referred to the components of the parallelogram of forces, the resultant of which would be the tow-line. I do not see the object of doing this. I think that a comparison of the actual tow-line pulls would be more satisfactory, especially as the angle made by the tow-line with reference to the course of the towing motor would vary but little.

The tests recorded, show that a tractor weighing 6493 lb., and getting its tractional friction from the pull on the tow line, is not so efficient as a mining electric locomotive weighing 16,000 lb. The tractor exercised a greater resistance to its own propulsion than a mining electric locomotive of over twice its weight. The experiments demonstrated that a " tractor must have a pressure made upon the wheels equal to the weight of a locomotive that will give similar traction ". It is evident that a tractor that gets its tractional friction independent of its weight, or independent of a friction that would impede its progress to the same extent as that of a locomotive of sufficient weight to give a similar traction, would be much more efficient than either of the types of motors tested. In designing the motors for the tests on the Erie canal, and the Finow canal in Germany, I succeeded in producing an efficient motor, working independently of its weight. The lighter it can be built, the more efficient it becomes. These motors are described and illustrated in the New York State Engineer's reports, also in the TRANSACTIONS of this Institute and those of the American Society of Civil Engineers.

The motor tested on the Finow canal in Germany weighed 1984 lb. It carried a 5-h.p. motor. It pulled the loaded boat with ease at the speed for which it was geared to run, namely, 2.5 miles per hour. The tow-line pull was 575 lb. The electric motor did not consume its full quota of watts. This was done on a cableway track. If a low I-beam track were used, the efficiency would have been greatly increased, as the motor would not have had grades to climb on approaching the supports. With such a track, this towing system would be ideal, especially if single-phase current were used for the electrical transmission.

C. P. Steinmetz: During the rapid expansion of our railway system, the canals had to take a rather secondary position, but it is gratifying to know that general interest in canals and in water transportation is reviving, and that the government is considering the improvement of the Mississippi waterway, and that the state of New York is rehabilitating the Erie canal.

What would be still more interesting than the paper is, not merely a comparative test of two rival systems, but a comprehensive paper covering the subject of canal haulage; that is, a comparison of the relative advantages, efficiencies, financial economies, etc., of the different systems of electric haulage, of steam propulsion, and of other methods, which have not been mentioned. Other methods are the chain drive, where a chain is laid at the bottom of the canal or river, and raised up to propel a boat, carried over a drum, and dropped again. I understand that this system gives good service abroad. And let us not overlook the *mule*. Mule propulsion of a canal boat appears to be a rather antiquated method, but we may find, nevertheless, that mule power, is, after all, under some conditions, the most economical form of drive. Comparing the cost of electric power per ton-mile as given in the paper with the cost of maintaining the same mule power, I should not be astonished to find that under the average conditions of canal haulage, the mule is the cheaper power. I am told that mules are cheap to buy and maintain, and are long-lived.

In systems of canal haulage a condition essentially different from that of the railroads has to be met, in that most of the canals are public highways; that is, any boat has a right on them just as a cart has on a public street. A railroad company has exclusive control of its right-of-way. Electric propulsion, then, must not interfere with mule or steam propulsion, or any other established method of propulsion on the state or national canals. Financially, the most serious feature is that canal traffic, in very many cases, is extremely light and intermittent. It exists only for part of the year, and the traffic varies considerably from year to year. Any equipment installed to take care of the maximum traffic would lie idle a part of the year, and might be very uneconomically used during some years. Under such conditions an electric system may be rather uneconomical. One of the chief advantages of the canals is the greater independence of the railroad which they confer.

It appears to me, therefore, that to show a superior efficiency to other forms of haulage, the field which electric haulage would cover, the traffic which it would take care of, would not be the traffic which exists now on waterways like the Erie canal, but a new form of traffic which would probably be created. The trolley lines have not taken the traffic of the steam railroads, but built up a new traffic; and I can well see that it might be possible to establish a profitable system of electric haulage on the numerous waterways of the country. A further careful investigation of the subject would be of considerable interest and of great benefit to the engineering profession.

L. B. Stillwell: The comparison of the two traction engines that we have made has resulted in certain determinations of comparative energy required and of actual energy required which have an application wider than we have attempted here to give them.

As regards efficiency of the contrasted machines, while the difference in favor of the locomotive is not controlling, it should not be minimized too far. Table 5 evidences clearly that from the mechanical standpoint the tractor is materially less efficient than the mining locomotive. While the difference in losses is small in comparison with the total energy utilized, it is large when expressed in terms of losses. For an effective pull of 2000 lb., for example, the mining locomotive loses an equivalent pull in the machine equivalent to 400 lb., while the best of the tractors loses 600 lb. The lesson to be drawn is that the tractor needs mechanical improvement.

With reference to Dr. Steinmetz' remarks in regard to a broader treatment of the subject than is attempted in this paper, I would say that in the course of the same investigation upon which our paper is based we studied the economy of the electric haulage system as compared with haulage by mules and established, to our own satisfaction at least, that if a canal is worked at anything approximating its full traffic capacity, electrification will pay handsomely.

In the case of the canals of the Lehigh Coal and Navigation Company, assuming some improvements in certain locks and an increase of traffic to a point approximating the full capacity of the canal, we estimated that the cost of operation, including all capital charges, could be reduced below one-half a cent a ton-mile. The grand average cost of freight transportation in the United States by railroads slightly exceeds 4 mills per ton-mile without any capital charges, locomotive repairs and renewals, being charged generally against cost of operation. It is safe to say, therefore, that if these canals were worked to their full capacity, even with the small barges now employed, the cost of transporting freight per ton-mile will closely approximate the average result attained in steam railroad practice to-day. With larger barges and larger locks, the cost of transportation would be further reduced; but everything depends, as Dr. Steinmetz suggests, upon the amount of traffic. The occasional mule is a proper engine when the traffic is very light, but if the traffic can be worked up to a reasonable extent it will pay to electrify. The capital costs when divided by a very large number of ton-miles per annum are reduced to so small an amount that they are absorbed by the general economies resulting from electrification.

A paper presented at a meeting of the Pittsburgh Section of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 1, 1908.

CHARACTERISTICS OF MOTORS FOR LARGE SHEARS

BY BRENT WILEY

The function of a fly-wheel in a system with a rapidly fluctuating load is to equalize the power requirements, thus reducing the sudden shocks to the moving parts and thereby the strains on the machine frame and both the mechanical and electrical strains on the driving motor. For the fly-wheel to be effective the speed characteristic of the motor should be such that the motor will slow down as the load increases and will increase in speed as the load decreases. In the case of large shears the full working load is applied suddenly and the fly wheel is called upon to deliver energy through a very short space of time, varying from one-half a second to two seconds, according to the size of the machine and the size and condition of the material cut. Thus it is evident that the speed characteristics of the driving motor must be inherent, as the time is too short to depend upon a practical control means for changing the motor characteristics.

The ideal working condition for motor-driven shears would be one in which the fly-wheel does all of the cutting work, leaving for the motor only the friction load and the work of accelerating the fly-wheel after the cutting and subsequent slowing down period. The results of a test made on a large bloom shears, which is referred to later, show that this ideal condition can be approximated very closely when the speed characteristics of the motor are properly chosen.

Before outlining the exact conditions which the motor speed characteristics should meet, it would be well to analyze the speed curves of a shunt, a standard compound, a 50 per cent compound, and a series direct current motor. These curves as shown in Fig. 1 are designated by the letters *A*, *B*, *C* and *D*, respectively, and are given for a 50 h.p., 220-volt, direct-current motor.

For shears requiring a motor of 25 h.p., or of larger capacity, the friction load will approximate 25 per cent of the motor rating; for smaller shears the friction load varies from 15 per cent to 20 per cent of the full load.

The speed variation for a given change in load and the percentage of energy given up by the fly-wheel for the respective changes in speed are as follows:

Curve A.

Shunt motor, speed variation from light to full load. 5 per cent.
The energy of a fly-wheel varies as the square of the speed and the amount given up for 5 per cent speed variation is .... 10 per cent.

Curve B.

Standard compound motor, speed variation from light load to full load .... 15 per cent.
Standard compound motor, speed variation from friction or 25 per cent load to full load .... 10 per cent.
Energy given up by fly-wheel for 10 per cent speed variation .... 19 per cent.

Curve C.

50 per cent compound motor, speed variation from light to full load .... 50 per cent.
50 per cent compound motor, speed variation from friction or 25 per cent load to full load .... 30 per cent.
Energy given up by fly-wheel for 30 per cent speed variation .... 51 per cent.

Curve D.

Series motor, speed variation from 25 per cent load to full load .... 66 per cent.
Speed at 25 per cent load .... 1500 rev. per min.
Speed at full load .... 525 rev. per min.

With but few exceptions the electric motor drive is now used in all machine shops, and the replacing of worn-out engines with motors for individual and group drive is completing this evolution. Where such a change is to be considered in regard to engine-driven shears, it is comparatively a simple matter for an engineer to determine the size of the motor and the proper speed characteristics to give the best results. For example, in the case of a large hot bloom shear

The fly-wheel capacity of the machine .... *A* h.p. seconds.
Friction load of machine .... *B* amperes.
(obtained by test) .... (at a given voltage)
Cutting period .... 2 seconds.
Period between cuts .... 6 seconds.
(This cycle is to be considered continuous.)

If the power is cut off when the machine is running light at full speed, the number of consecutive cuts that can be made before the machine comes to rest is four. For the ideal case, where the fly-wheel does all of the work, it should give up 25 per cent of its energy per cut and must slow down 13 per cent.

Let the light load of the motor = C rev. per min.

During the cutting period the speed must fall to C rev. per min. 100 per cent − 13 per cent = 87 per cent C rev. per min.

Energy delivered by the fly-wheel during two seconds' cutting

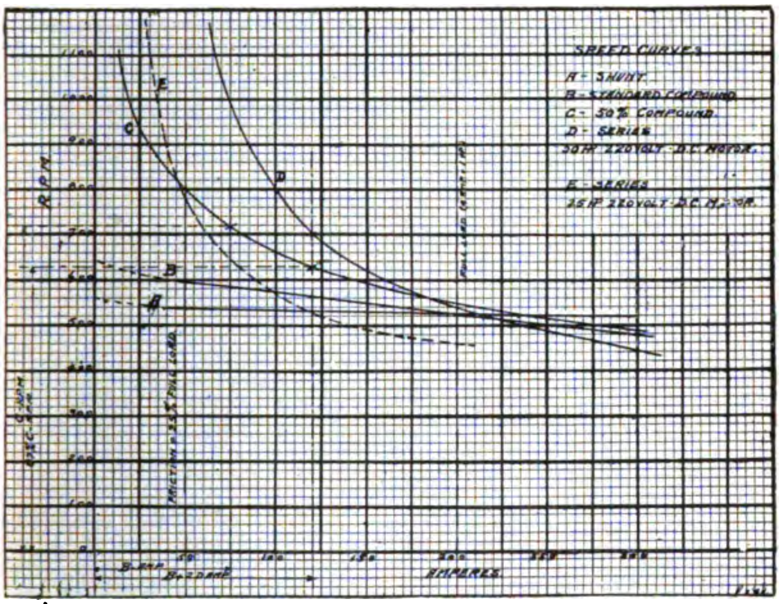


FIG. 1

period and energy stored in the fly-wheel during the six seconds interval = 25 per cent A h.p. seconds.

Let the average current required to store 25 per cent A h.p. seconds energy in the 6 seconds interval = D amperes.

The current curve which corresponds to the power curve with constant voltage will vary through an economical range when the motor speed-characteristic governs the variation as follows:

The minimum value of the current should be equal to a friction load at the end of the interval between the cuts. The maximum value of the current should be equal to the friction load plus twice the value of the average current required to store the fly-wheel energy expended during one cut. The curve in Fig. 2 illustrates this.

During the cutting period the current rises to a maximum value as shown at point X, and falls to a frictional load value as shown at Y at the end of the 6-sec. interval. Thus, at the point Y, B amperes corresponds to C rev. per min., and establishes one point on the motor speed curve. This shows that it

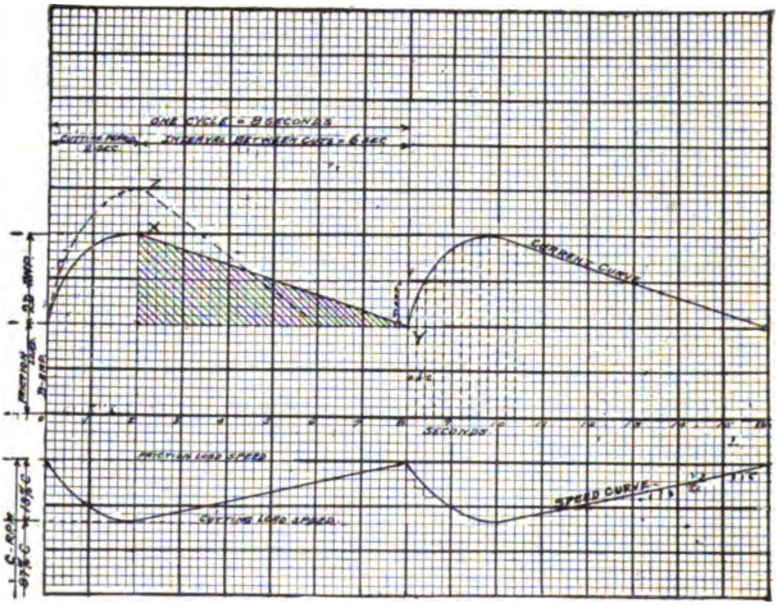


FIG. 2

requires D amperes as an average to store the 25 per cent A h.p. seconds energy in the fly-wheel. Thus the maximum value of the current at point X equals 2 D amperes, which must correspond to 87 per cent C rev. per min., and a second point on the motor curve is established. By this means a speed curve for the working range required can be plotted. As an illustration, these points are designated on curve C, Fig. 1.

The heating effect of the motor load varies as the square of the current and is represented by the square root of the mean square current. This value of current can be closely approximated by dividing the current curve into a number of parts along the time ordinate, squaring each sectional current value and multiplying by the time-increment. These several values are then added and the sum divided by the total time period. The square root of this dividend is the square root of the mean square current. For example, refer to Fig. 2.

Square root mean square current

$$= \sqrt{\frac{(a^2 \times 0.2) + (b^2 \times 0.2) + (c^2 \times 0.2) \text{ etc.}}{8}}$$

and this is the value of a continuous current which would produce the same heating effect as the varying load shown. The capacity of the motor required for the above condition can thus be calculated.

With the principal portion of the speed curve constructed and the capacity of the motor known, the next point for consideration is the type of motor winding and consequently the speed characteristic which is best suited for the given conditions.

As has been explained before, the speed variation of a series motor covers too great a range between the friction load, or 25 per cent full load, and the working of full load of the motor. This value is approximately 66 per cent, and therefore the series motor can be eliminated from the list.

The next motor to be considered is one with a 50 per cent compound winding, in which case the full-load speed is 50 per cent of the light-load speed.

Fig. 3 is a recorded current curve of a 50 per cent compound motor operating a large bloom shears which has the following characteristics:

Style of machine	Vertical, bloom.
Maximum section the machine will cut	10 in. by 10 in.
Weight of fly-wheel	20,000 lb.
Diameter of fly-wheel	9 ft. 10.5 in.
Section of fly-wheel rim	12 in. by 13 in.
Rev. per min. of fly-wheel	110
Energy of fly-wheel at friction load	2500 h.p. for 1 sec.
Size of motor	50 h.p., intermittent rating.
Voltage of motor	220
Type of motor winding	50 per cent compound.
Motor	direct-current, geared
Motor speed	500 rev. per min. full load.
Friction load	50 amperes, 235 volts, 800 rev. per min.
Cutting load, maximum	110 amperes, 235 volts.

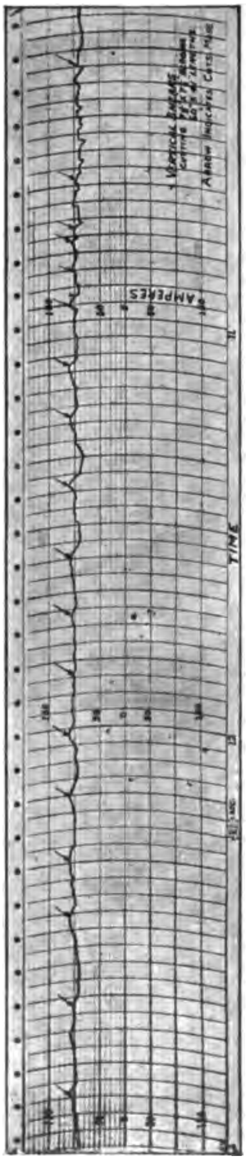


FIG. 3

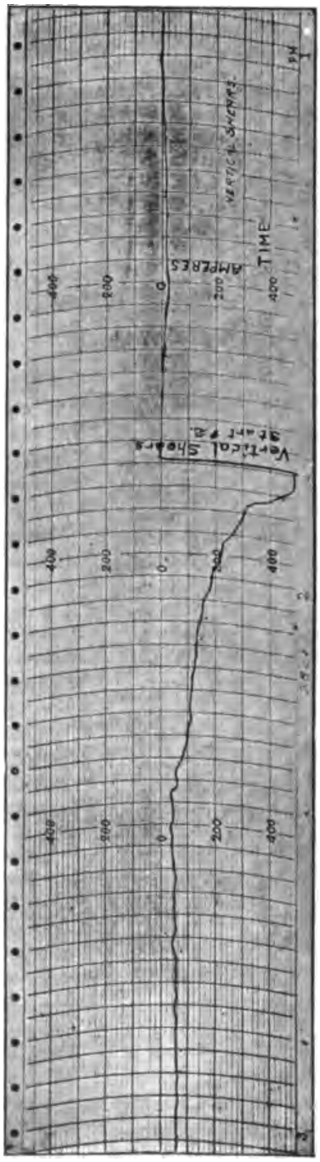


FIG. 4

Section of material cut......................7.5 in. by 7.5 in.
Kind of material cut..............................hot steel
When the machine is running light at full speed and the power is cut off the number of consecutive cuts that can be made before machine comes to rest is four.

Motors used for intermittent duty, such as street car and crane service, are given an intermittent rating and will operate at full load for one hour without injurious heating; this heating is generally stated as 75 degrees cent. rise above the surrounding atmosphere. The above motor is rated on this basis, and the continuous load which it will carry with the same temperature rise is equal to practically one-half of the 1-hr. rating.

As shown on the curve, the motor is working between an average minimum load of 95 amperes and a maximum of 110 amperes. Estimating on the square root of the mean square basis, the equivalent heating current is approximately 100 amperes at 225 volts; this requires a 25-h.p. motor, continuous rating, or a 50-h.p. motor of intermittent rating.

The starting conditions as shown in Fig. 4 require a maximum of 100 h.p. which falls gradually to the friction load of 125 h.p. in 40 sec.

The curve in Fig. 3 shows virtually a uniform load on the motor, a much greater load than that given for the theoretical case in Fig. 1. An analysis of the condition shows, however, that the motor is working in a very steep portion of its speed curve; and the speed change for this working portion of the 50 h.p., 50 per cent compound-wound motor of intermittent rating is equal to 75 per cent of the speed change of a 25 h.p. series motor of continuous rating.

50 per cent compound motor 95 ampere 670 rev. per min.
" " " " 110 " 640 rev. per min.
Reduction in speed................ 30 rev. per min. = 4.5 per cent.
Series motor.............. 95 ampere 580
" " ....110 ampere 545
Reduction in speed................. 35 rev. per min. = 6.0 per cent.

The steeper the speed curve the more gradual is the fall of the current curve from the peak to the minimum value. Referring to the theoretical curve in Fig. 2, a motor with a certain percentage of compounding will require a maximum current, as designated at point X, to give the required speed change of 13 per cent; a motor with less compounding will require a maximum current rising to point Z for the same speed reduction. The shaded portion of the curve from point X to point Y represents the work done in restoring energy to the fly-wheel. It is obvious that an increase in the peak load or vertical component causes a corresponding decrease in the horizontal or time ordinate, as the area described by the curve beyond the peak remains constant. Therefore the steeper the motor speed-curve the more gradual the decrease of current value between the cutting periods. On account of this sluggish characteristic, it requires quite an appreciable time, virtually 14 seconds, Fig. 4, for the motor described above to increase the speed of the fly-wheel from the speed corresponding to 110 amperes to that corresponding to 50 amperes, or friction load. As a cut is made in about every 9 sec. the minimum value of the current does not reach the friction load. This is the principal reason why the obtained load curve is so much smoother than the theoretical curve of Fig. 2.

For the particular application given above, the 50 per cent compound motor proves to be a fairly good series motor regarding speed characteristics; it requires only a slight increase in load to give the speed reduction required by the fly-wheel in order that it may do the greater portion of the work. Compared with its continuous electrical capacity, this type of motor has great mechanical strength, and it is capable of standing heavy overloads for a short period of time. Thus it is apparent that both mechanically and electrically this motor has better characteristics than the motor of continuous rating for a heavier kind of work.

The curve of Fig. 5 shows the working load of a hot bloom shears driven by a direct-current, 220-volt motor of 25 per cent compounding. The general characteristics of the machine and motor are as follows:

Style of machine	horizontal bloom.
Maximum section the machine will cut	10 in. by 10 in.
Length of blade travel	15 in.
Rev. per min. of cam or crank-shaft operating blade	17 at 850 rev. per min. of motor.
Weight of fly-wheel	12,700 lb.
Diameter of fly-wheel	8 ft.
Section of fly-wheel rim	10 in. by 12 in.
Rev. per min. of fly-wheel at friction load	350
Energy of fly-wheel at 350 rev. per min.	5900 h.p. for 1 sec.
Size of motor	125 h.p.
Type of winding	25 per cent compound.
Motor	direct-current, geared.

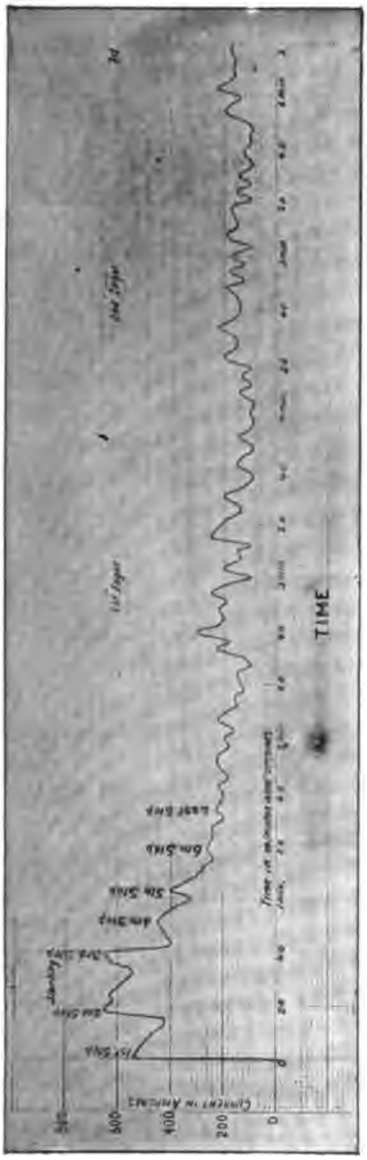


FIG 5

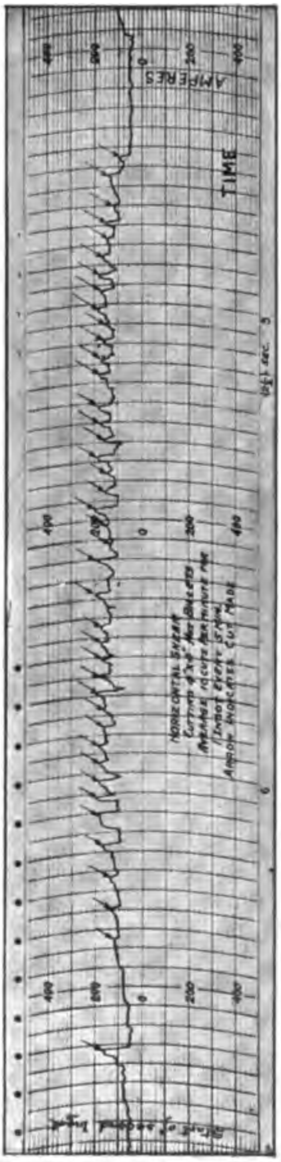


FIG 7

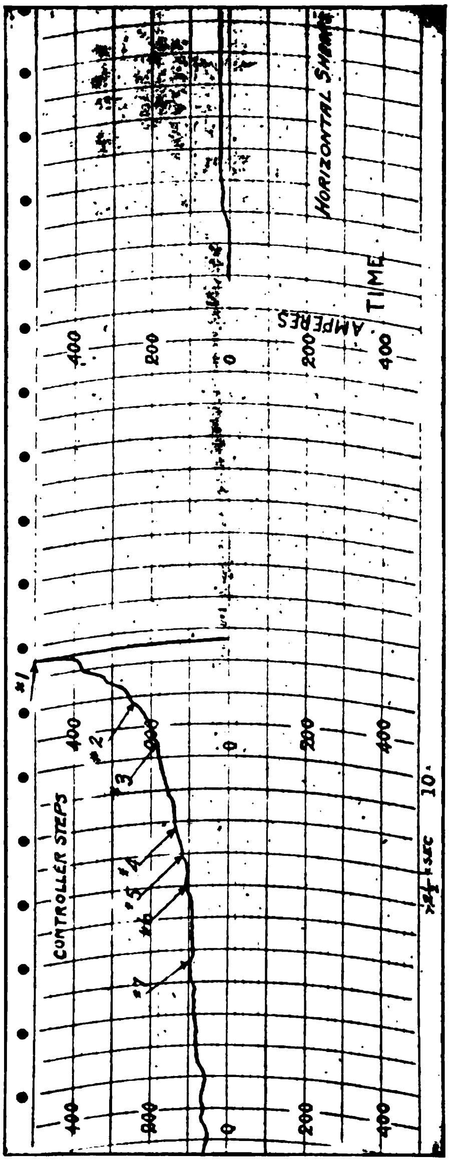

HORIZONTAL SHEARS
TIME
AMPERES
400
200
0
200
400
CONTROLLER STEPS
#1
#2
#3
#4
#5
#6
#7
10

Fig. 6

Motor speed....................660 rev. per min. full load.
Friction load......100 amperes at 225 volts, 850 rev. per min.
Cutting load.......................200 amperes, at 225 volts.
Section of material cut.....................8.5 in. by 7.25 in.
Kind of material cut............................hot steel.

When the machine is running at full speed and the power is shut off, the number of consecutive cuts that can be made before machine comes to rest is four.

The curve was plotted from readings taken at 3-sec. intervals The current reaches a maximum value of 300 amperes and is much more fluctuating than that indicated by the curve of Fig. 3, although the fly-wheel effect is more than double. With a motor of increased compounding the load fluctuation could be materially decreased.

The current would have excessive peak values with either a standard compound or shunt motor, although it has been found in some cases that for the same work done the heating effect on the standard compound motor was 25 per cent less than that on a shunt motor.

Increasing the fly-wheel capacity of the system has the same effect on the load curve as increasing the compounding of the motor, and it will consequently tend to flatten the load curve. If the fly-wheel capacity is decreased the load becomes very fluctuating, which is the same as decreasing the compounding of the motor, giving it a flatter speed curve. Fig. 6 shows the starting current and Fig. 7 the running current of a hot bloom shear driven by a motor of standard, or 15 per cent, compounding. If the fly-wheel capacity of this machine or the compounding of the motor were increased, a flatter current curve would be obtained.

Horizontal billet.

Maximum section the machine will cut.........5 in. by 5 in.
Rev. per min. of cam or crank operating blade............28
Weight of fly-wheel.............................3000 lb.
Diameter of fly-wheel.............................5 ft. 6 in.
Section of fly-wheel rim......................14 in. by 3 in.
Rev. per min. of fly-wheel.............................190
Size of fly-wheel.................................60 h.p.
Voltage of motor.....................................220
Type of winding.......................standard compound.
Motor...........................direct current, belted.
Speed of motor............................640 full load.
Cutting load,,......................45 amperes at 230 volts.

Section of material cut........................4 in. by 4 in.
Kind of material cut...........................hot steel.

When the machine is running light at full speed and the power is cut off, the number of consecutive cuts that can be made before machine comes to rest is three.

Alternating-current Motors for Shears

The motors considered are designed for either 25-cycle or 60-cycle, three-phase circuits and are of the induction type. When it is necessary to start a fly-wheel type machine frequently, the motor should have a wound rotor provided with slip rings and external resistance for control. This type of motor gives very good starting conditions, as full-load torque is obtained at approximately 1.25 times full-load current as compared with 3 to 3.5 times full-load current for full-load torque with a squirrel-cage rotor.

Shears are usually operated continuously, so the starting current required is not of particular importance. It is desirable to have a motor of simple construction for continuous duty, and although some sacrifice is necessary regarding starting conditions, an induction motor with a cage secondary should generally be used for operating shears. The motor should be provided with high-resistance end-rings, as this form of construction gives very good starting conditions. As a maximum a 50 per cent increase in torque with a 30 per cent decrease in current and a 6 per cent decrease in efficiency at full load may be obtained. A second advantage in using high-resistance rings is that the motor has a speed characteristic very similar to that of a direct-current compound-wound motor, thus allowing the fly-wheel to be effective during the cutting period.

The amount of resistance that can be included in the end-rings without undue heating is limited, as this heat energy must be dissipated in the motor. Where the motor operates continuously under virtually full load the maximum slip that can be obtained with high-resistance rings is approximately 10 per cent; but for intermittent service the slip can be increased to 15 per cent without undue heating. The efficiency and power curves of the motor will be similar to those of a standard direct-current shunt-wound motor having sufficient resistance in its armature circuit to give 15 per cent drop in speed from light to full load; in other words, the slip of the motor varies according to the resistance in the end-rings. As the fly-wheel effect obtained from the system varies as the square of the speed at the high and low points during the cutting period, a slight increase in the resistance will produce a material reduction of the maximum load on the motor.

In shearing plates, the load is applied gradually and a motor with 15 per cent slip will have a fairly smooth load curve, the fly-wheel being of liberal proportions. In the cases of hot bloom and scrap shears, where the section to be cut is quite large and practically square, the nature of the work becomes more severe. The actual cutting period is short and the power required large, which makes it necessary to include large fly-wheel capacity; and in order to prevent excessive loads motor should have a steep speed-curve. In the case of direct-current work it has been shown that increasing the compounding of the motor to 50 per cent has materially improved conditions, giving in the case shown almost a uniform load curve. For induction motors, however, 15 per cent slip is a practical limit, therefore to reduce the peak load for the heavier classes of machines fly-wheel capacity must be added.

In any class of machines where the load is intermittent, especially when cast tooth gears are used in the reduction, the driving motor will be subject to considerable vibration. In many cases it is necessary to mount the motor on a frame or bracket support, although it is difficult to provide sufficient rigidity with this construction. This vibration causes undue wearing of the motor-bearings and tends to deteriorate the rotor-windings. The most effective way to prevent this vibration where gearing is to be used is to mount flexible coupling between the rotor and the driving pinion, which is keyed to a short length of shaft supported by two bearings. This form of construction has been adopted for a number of different drives where the work is very severe. It gives excellent results with little wear of the coupling parts and shows a decided decrease in motor maintenance.

The starting conditions are rather severe when the machine has large fly-wheel capacity and for shears as described above. The motor-starting apparatus should be of liberal capacity and should be provided with protective means to insure a gradual starting of the motor, thus preventing excessive starting currents. An autostarter is used for this work.

The starter consists of a double-throw, oil-immersed switch with the autotransformers mounted in the same case. Several extra taps are provided so that the most suitable starting condition can be obtained. In starting, the handle of the autostarter is first thrown to the right which closes the switch on the starting side. A lock is provided to prevent the handle from being thrown in the wrong direction, and unless held in position by hand on the starting side it will return automatically to the off position. After the motor has attained a nearly constant speed the handle is thrown quickly to the left and is locked automatically.

Fuses or a circuit-breaker may be employed to protect the motor against overloads while running, and these can be so connected that the starting current may exceed the running current without blowing the fuse or tripping the circuit-breaker.

Where there are a number of motors to be started, as in a steel mill, it is a practical arrangement to provide a single transformer centrally located for each group of motors. The transformers should be supplied with an extra tap to give approximately 65 per cent line voltage; for three-phase motors five line wires would be required for the motor feeder circuit. Thus instead of a number of individual transformers, one transformer of large capacity is used and the starting apparatus is limited to a double-throw switch.

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THE ENGINEER'S ACTIVITY IN PUBLIC AFFAIRS— PUBLIC UTILITY COMMISSIONS AND FRANCHISE VALUATIONS

BY HENRY FLOY

Americans are, in a mild way, extremists. They start for the goal with such impetuosity and zeal that they often overrun the mark and then have to return to it. This is what is now happening to public opinion with reference to the corporations. No language is strong enough to express the public condemnation of corporate mismanagement, usurpation of power, and larceny of funds, which have recently been committed. On the other hand, all public utility corporations are not bad; and the engineer, knowing this, should be among the first to oppose the illogical, unreasonable condemnation of our present commercial system which causes a loss of the confidence on which our business relations are founded, and results in weakening the foundations of our whole economic structure.

As President Woodrow Wilson has truly said:

> Scathing indictments of our present industrial and political conditions are what we are suffering from at the present moment and they are to be offset, not by other scathing indictments, but by a very calm and self-possessed examination of actual conditions of things. What we need at present is not heat but light.

As a matter of fact, public sentiment is now undergoing a reaction; the American sense of right and fair-play is winning. The pendulum has reached its extreme position and is starting to swing back. The excesses in which the public mind has been indulging, indicated by the cry for indiscriminate municipal ownership, governmental and socialistic rule, are being replaced by a more sane demand for control and regulation.

It is beginning to be recognized that a corporation must not only serve the public but also the stockholders; that the public cannot be served by corporations unless the stockholders receive a return on their investment concomitant with the risk; that capital cannot be compelled to invest on terms unacceptable to it. This change of sentiment, however, does not mean, as is clearly evident to the well-informed engineer, that the public will ever again return to its former *laissez faire* policy toward corporations.

Just at this time, during this important readjustment of relations between the public and the corporations, it is proper, yes necessary, that the engineer should pause to consider the lessons to be learned from recent experience, formulate his opinions for the future, and thus be the better prepared to coöperate in ending the present feeling of unrest and antagonism and share in the successes of the new advance which is sure to begin soon. Although by education, training and experience the engineer is presumably well-balanced and not excitable, he may nevertheless be influenced by popular sentiment or the demands of the corporations or financiers. During this transition stage especially, when the demands upon his time are restricted, he should take the opportunity to verify his opinions, reestablish his conclusions, and calmly determine his future line of action.

With these thoughts in mind, this paper has been prepared to serve as an introduction to a discussion which it is hoped will help to a crystallization and unification of the ideas of the members of the Institute on but three, of many similar important non-technical questions now demanding the serious consideration of broad-gauge engineers; namely, activity of engineers in public affairs, public utility commissions, and franchise valuations. The author's comments must not be taken as an attempt wholly to cover the subjects touched upon, or to reach conclusions which may not require modification, as the questions considered could very properly occupy the attention of the Institute at more than one session and they present viewpoints almost as diverse as is its membership.

Activity of Engineers. Considering the importance of the real work done by the engineer in the recent commercial development of this country, the comparatively unimportant public part taken by him is rather striking. His inconspicuousness can probably be accounted for by

(a) His keen interest in the purely scientific aspect of the enterprises with which he is connected; with him a "blunder is a crime". The engineer, like the teacher or the ecclesiastic, has a certain love for his profession which absorbs and recompenses him, in a degree, independently of monetary reward or fame.

(b) His natural hesitancy in pressing his own claims to recognition. Most lawyers or politicians are ready speakers, used to argument, and therefore, by profession trained to make their own case a strong one.

(c) His lack, in the past, of a broad, general education, especially along the lines of history, political economy, and what Dr. Humphreys, of Stevens Institute, in a recent address, called "business engineering". A narrow, purely technical training does not conduce to a broad, liberal consideration of any subject.

(d) His too frequent inability to speak fluently in public. The engineer does much of his work individually, quietly, on paper, so that he often becomes embarrassed when called to express his opinion from the platform.

As a result of these limitations the engineer has hardly received the public recognition which would be expected. Perhaps the most striking recent illustration of this was in the appointments made to the two Public Utilities Commissions of the State of New York, which included fourteen high-class, well-paid officials. Of this number only one has had a technical training, although in the hands of these commissioners are placed, with almost despotic power, the affairs of large engineering enterprises in the State of New York, estimated to be valued at about $3,500,000,000. This exception is the more noticeable when it is considered that the same governor, in naming the Hepburn Commission to inquire into and report with recommendations as to the condition of banks, financial affairs, and their improvement, selected bankers; and, when a commission was named to consider and make recommendations with regard to the Torrens system of registration of land titles, the commission was almost entirely made up of men prominent in real estate matters. Mr. George W. Perkins, in a recent address, referring to a commission to have national supervision of railroads, said:

> It should be in the hands of experts. A railroad commission, for instance, should be composed of railroad men who can deal with the questions arising in a practical way. This kind of expert, high-minded super-

vision would not be opposed by the business interests of the country. What they dread is unintelligent, inexperienced administration.

Mr. Perkins but expresses the accepted opinion that experts are the proper parties to have supervision of matters in which they are specialists. Even the New York State Court of Appeals, in a recent decision relating to the constitutionality of the statute creating a commission to determine rates, says:

That the most appropriate method (speaking from a practical, not necessarily constitutional point of view) is the creation of a commission or body of experts to determine the particular rates has been said several times in the opinions rendered by the Supreme Court of the United States in the various railroad commission cases and in those of State courts.

It is well known that the House of Lords in England, when it sits as a Court of Appeals, has the cases submitted to its law members, which would seem to be the only rational practice. Contrary to such general belief, the opinion prevailing in selecting the New York State commissioners, as indicated by their appointment, was that if they possessed unquestioned integrity there existed no special reason for naming men experienced in handling engineering or transportation questions. This has resulted in the necessity of hiring engineering subordinates, which increases expenses and decreases direct responsibility, because the advice of more or less independent experts reporting on matters of detail is quite different in value from the advice given by a technical member of a board identified with its policy and responsible to the public for the discharge of his obligations. Hired experts can never be made to shoulder the responsibility for a decision rendered by a commission composed wholly of men untrained in public utility affairs and perhaps unable fully to appreciate the technical effect of their orders.

It is noteworthy that much of the work of the commissions is divided, one member investigating one question and a different member another. With two or three commissioners as engineers, the engineering questions would naturally devolve upon these members, and they could solve them much more quickly and unequivocally than could politicians, lawyers, or business men unacquainted with even the terms involved, to say nothing of understanding the practical conditions under which a lighting corporation, or steam or electric railway company, must operate. A perusal of the minutes of the hearings held before state commissions will convince any unprejudiced person that a disproportionately large amount of evidence and testimony is submitted, with consequent unnecessary financial expense and consumption of time for the purpose of explaining terms, apparatus, and methods of operation and expenditure to commissioners who, in general, should be acquainted with the matters being considered. This and similar evidence surely indicates that the efficiency of the commissions is largely reduced by lack of proper make-up. For this condition of affairs the engineers themselves are partly to blame.

The antiquated notion that every engineering expert is unable to appreciate any question outside of its purely technical significance is disproved by the fact that the success of the engineer is often based on a liberal education with wide experience, giving him a capacity for proper consideration not only of technical but also of commercial and political factors that enter engineering undertakings, and also by the fact that the administrative and executive staffs of many of our largest and most progressive organizations are being constantly recruited from the engineering profession. To become president of the Pennsylvania Railroad, judging from precedent, one must have, in addition to other qualifications, both a technical education and practical experience in engineering work.

By reason of the work and position of the engineer in the business and technical world, is it not reasonable to expect that at least one-half of the membership of the public utility commissions, being named from time to time throughout the country, should be composed of experienced, broad-gauge engineers. I venture to prophesy that as public service commissions become more common, they will be constituted more and more of men drawn from the ranks of those having practical experience with the work to be undertaken. In fact, I can conceive of no more independent, dignified, influential or beneficent occupation in which an engineer can be engaged, and I believe the honor of the position will ultimately attract to it our most capable men whom now the monetary inducement will not interest. The present inertness of the profession in these matters is noticeable. Last spring the writer personally sought to have the officials of some of our engineering clubs and societies develop sentiment looking to action on the part of these respective organizations toward obtaining the appointment of some men of engineering experience on the New York State commissions, but only one organization acted. The public utility corporations themselves, represented by a number of executive officers in conference, showed some interest in securing commissions capably constituted, but no definite results came from the conference. Even the labor unions have actively urged they be represented on the commissions, simply on grounds of self-interest, while the engineer, with especial qualifications for the work, has too much pride to ask recognition, even with semi-altruistic motives. It is a hopeful sign that for the first time in its history the American Society of Civil Engineers recently memoralized Congress, urging legislation for the preservation of our forests, a precedent which might well be followed by the Institute.

The importance of the engineer in commercial transactions is steadily growing, and he should recognize the claims upon him to take part in public affairs and assume the responsibility more and more laid upon him, of leadership. His increasingly closer business relations with public matters and his reputation for integrity give his opinion and influence steadily greater weight in large affairs, which he should appreciate, accept, and respond to. While the engineer's work must always be professional, in a way judicial, and should always be accompanied by high moral sense, the successful engineer must nevertheless combine practical business qualifications with his scientific work. There can be no good engineer—in a broad sense—unless combined with his technical conclusions there is included such recognition of commercial conditions, as will thereby permit him to attain the worthy objects of his chosen profession with maximum efficiency.

Public utility commissions. The aggressive, almost insolent, and oftimes unfair attitude of some utility corporations has created an insistent demand for further and more direct control of operations than has been possible through the more usual form of legislative enactments. The American people are not, as a rule, over inquisitive as to somebody else's business, but when imposed upon, they do not hesitate to ascertain the why and wherefore. The result has been a publicity of corporation finances and affairs that now implies an obligation to afford the corporations legitimate protection in their business.

The necessity for regulation by the public arises, in the first place, because the exercise of franchise rights by certain corporations, while academically not exclusive, is nevertheless practically non-competitive; therefore, one of the ordinary checks arising through competition does not in such cases apply. Unlike the individual or ordinary business corporation. a public utilities corporation frequently cannot begin business without being organized under special and specific laws. Such corporations may be granted unusual franchises; for example, the right of eminent domain, and are recognized as existing for service to the public in a manner, and with privileges entirely unique and distinct from those of ordinary business undertakings, and are therefore acknowledgedly subject to special regulation and control. Even ordinary business corporations which have no special privileges granted, if uncontrolled, may, as the result of unusual commercial acumen linked with a large aggregation of capital—illustrated for example, in the case of the so-called " trusts "—create a wrong which organized society will very properly step in and limit, control, or prohibit. Business trusts are in effect monopolies, because competition as a practical matter is out of the question, and hence regulation in their cases is also essentially necessary. The underlying principle of monopolies, coöperation, is a legitimate product of our present civilization; it may be controlled but not prohibited.

In the second place, regulation of utility corporations competing for the same business is required from the very nature of the business itself. If they are allowed to compete fully and freely, experience indicates that they will ultimately engage in a war of annihilation, the expense of which is in the end borne by the security holder or the public. Up to a few years ago, political economists believed and argued that the only regulation required for all commercial operations was free and unrestricted competition:

> Because the experience of mankind had not developed essential monopolies, and it was believed that every problem which would arise would be solved by giving full play to the spirit of competition. * * *
> Whether that system of dealing with railroad corporations will succeed or not can be ascertained by viewing their history in the State of New York, and the experience which was had in this State, demonstrated that it did not work to the advantage of the public and that the evils connected with the system were simply enormous and unendurable. Competition could not exist upon railroads.*

Some years ago the state of Massachusetts appointed a Committee of Gas and Electricity empowered to inquire into and revise rates charged, operating costs, capitalization, and to limit competition. Although this commission was looked upon as something of an experiment, the high quality of work accomplished by it has commanded the respect and approval not only

* F. W. Stevens address, A. I. E. E. dinner, 1908.

of the public at large, but also of the corporations themselves which, through its protection, have been guarded against unfair and unnecessary competition.

Encouraged by the good work accomplished through this commission, and other commissions having to do with railroads, etc., and supported by those who were opposed to municipal ownership but believed that the conduct of corporations should be regulated and controlled, there has developed within the last year or two a popular demand for other state commissions with large powers that could compel, particularly railroads and gas and electric corporations, to comply with their obligations and furnish reasonable service at fair prices. Without attempting to discuss whether regulation should properly be undertaken by the state or federal government, it would appear that if intelligent regulation of such corporations as railroads is to be obtained, it must be done at least in part by the nation rather than through each state attempting to pass its own laws, perhaps contradictory to those of an adjoining state in which the same railroad must operate. On the other hand, state or even municipal control of gas and electric corporations might seem both logical and legitimate, provided the personnel of the board of control is capable, honest and unprejudiced. In fact, the corporations themselves, as a rule, welcome such regulation, as it will protect their properties from hostile and wasteful attacks, vicious competition, and unfair manipulation of its securities. Their objections are almost always based on either a fear of corrupt or dread of well-meaning, incompetent, and inexperienced men, as commissioners, or else that questions under consideration would be decided from the standpoint of the past rather than the present. For example, it would, of course, be unfair, to take advantage of the present investment of a corporation, of which the stockholders cannot unburden themselves, to make an unduly low price for its commodity. In each case the rate of return allowed a going corporation should be the same as that to a new corporation rendering the same service.

New York started in a mild way with several commissions for different purposes; but last year, under the leadership of Governor Hughes, the legislature passed laws substituting for the other commissions, two state commissions, one to have charge of all public utility corporations in Greater New York, and the other in the remainder of the state. To these two commissions were delegated almost unlimited authority, they having power to examine corporation affairs as completely as any board of directors, and to require changes in methods of operation and even reduction in prices charged for service.

Other states are following the precedent established by Massachusetts and New York. Wisconsin already has such a commission appointed under an act of the legislature, which is well worth perusal by any one desirous of learning the present-day radical trend of opinion. There is little doubt but that before long, *nolens volens*, most or all the states in the union will have commissions appointed to control and regulate at least the so-called public utility corporations. That such commissions have the right and power to determine rates, has been established in New York state by the courts, in the Saratoga case.

How, then, are these commissions to deal with the corporations in protecting the public, and at the same time give the investor every encouragement for profit, and the business no lack of opportunity? In this connection it is important that the engineer inform himself just what is the difference between operation, regulation, and confiscation.

With regard to operation, public utility commissions should restrict their action to general principles; they should not interfere with details, otherwise they will remove the present responsibilities from the shoulders of the directors to their own shoulders, restrict and hamper the efficiency of the organizations, still the incentive to work, and destroy the reasons for promotion of the employees—all of which will result in depreciating the service rendered the public and the financial standing of the corporations themselves. As has been well said:

> Regulation should stop where operation begins. Matters of business discretion should be left to the decision of those who are responsible for business results.*

If state regulation is to determine rates and limit the earnings upon investment, it may logically be asked, should the state not also include a guarantee of reasonable returns on the investment? If a corporation takes all the risks, it is logically entitled to all the profits. If the state prohibits anything more than a definite profit, may it not be morally bound to assure that profit? In fact, municipalities have been known to go a long way in this very direction by granting an exclusive franchise, which affords a monopoly and prevents competition.

* Report, Committee Public Policy, N. E. L. A., 1907.

The principle of state control is not new, although its application has recently been greatly broadened. We have become so accustomed to considering liberty as unrestricted license for all, that the statement of Chairman Stevens of the New York State Commission, at the dinner of the American Institute of Electrical Engineers in February, that the public can demand and take from the individual, much less the corporation, anything " from his pocket book to his life inclusive ", was as startling as true. The only precedent to the taking, is the public necessity and the proper manner and remuneration. In theory, then, regulation is correct, if only the practical application to the concrete case were not so difficult.

Confiscation means the taking of property without allowing " fair return " thereon. Fair return is a smooth legal term which neither the courts nor anyone else has yet been able precisely to interpret. In the decision of the United States Circuit Court in the Columbus case, an unallowed demand for a reduction in electrical rates, a decision with which every engineer interested in public utilities should be acquainted, it was stated that, over and above legitimate operating expenses and depreciation charges;

> The owner of the property should be at least permitted to receive as his compensation for its use the legal amount of interest allowed by the state of Ohio.

The court then goes on to say:

> It may well be doubted whether the legal rate of interest is reasonable and just compensation to the owner of the property devoted to public use, etc. * * * It may well be doubted whether capital would at any time for this legal rate alone be willing to enter upon the rendition of public service of the kind performed by the complainant under these circumstances and conditions., etc.

Again in the famous case against the Consolidated Gas Company of New York, in which a reduction was sought from $1.00 to $0.80 per thousand feet of gas. The court has held that the owner is entitled to " a fair return upon the reasonable value of his property ", which is guaranteed to him by the famous fourteenth amendment to the Constitution.

Apparently, the existing state commissions realize the importance of a comprehensive, thoroughly considered, and reasonable line of action based on " well settled principles of public policy "; and they feel the necessity of proceeding cautiously in order to establish correct rulings and avoid the charge of confiscation.

But the radical feeling of the time, as well as some unexpected conclusions, are indicated by certain rulings of the several state commissions with regard to public utility corporations. These are worth considering as illustrating general conditions which the engineer must bear in mind when advising his client as to investments and earnings.

The commission of the second district of New York states that they have:

> Refused to consider the application of foreign (other than those incorporated under the laws of the state of New York) gas and electrical corporations to do business in this state, and have announced it as a rule that no application will be entertained.

The Wisconsin statutes provide that only corporations organized under the laws of that state shall receive franchises therein. It seems to me that this is a somewhat narrow policy which can not be long continued without modification.

The same New York State Commission has decided to accept as satisfactory, unsealed electric meters having not more than 4 per cent. of error, although requiring gas meters to be within 2 per cent. of correct, and sealed by a representative of the commission. It is doubtful whether the leniency of the commission toward electrical operating companies will compensate the manufacturing concerns for the odious comparison made of the electric meter with the much slandered gas meter.

The same commission announces unequivocally that it will require each corporation to maintain a depreciation fund which must be provided out of earnings. This is a very wise conclusion required by the statutes of some states, and a step which many corporations have failed to take, as they should have done for the protection of their security holders.

In the Lockport decision the New York State Commission established an important precedent; they allowed the consolidation of two competing companies, but prohibited, as prescribed by statute, the issuing of securities to an amount exceeding the total capitalization of the two old companies. Thus it appears, losses resulting from a war of extermination and the increased cost of consolidation cannot be met by the issuance of new securities, as formerly, which is from one standpoint radical and far-reaching. Again, the commission ruled that the low prices reached through competition should not be increased after consolidation, the consolidated company agreeing in writing not to raise rates except with the consent of the commission, after further rehearing, which precedent, if uniformly followed, while protecting the public, possibly might tend towards bankruptcy for some consolidated companies.

As the result of its experience, the Massachusetts Gas and Electric Light Commission has recently reported that it finds the benefits of the consolidation of gas and electric companies in cities of considerable size do not compensate for the disadvantages to the public arising from such consolidations.

The engineer, of course, well knows that it costs more per unit to deliver gas or electricity to the small consumer than to the large consumer, yet the New York Commission of Gas and Electricity that went out of existence last July fixed a maximum kilowatt-hour charge to be made by the Rockland Light and Power Company in Orangetown. It has been shown that out of 112 customers served at a loss under the rate formerly charged, 75 would receive service under the new rate at a greater loss to the company; while out of 26 served at a profit, 19 must be served at an increased profit to the company in order to make good the losses increased by reduction of price to the 75 mentioned above. It is hardly necessary to say that the courts would not sustain this ruling, as was proved in the well-known Columbus case. The present commission has, by petition, taken under consideration an order to restore the old rates.

A consideration of the rulings of state commissions shows a tendency to place all corporations on the same footing as regards the returns to investors; that is, regardless of whether capital has been invested in a judicious and intelligent manner or in an inefficient way, the precedents established indicate that about the same profit will be allowed in either case. This, of course, does away with all incentive to improve the earnings by cutting down operating expenses, or to decrease the price, or introduce new apparatus or modern methods. It removes the stimulus heretofore existing with the individual, to make the very best showing possible, and hence is a reasonable, valid, and practical objection to control by commissions. One method of offsetting this very decided disadvantage has been evolved by the application of the London sliding scale, so-called because originating in London, England, and now in use in Boston. The principle is a profit-sharing one, in which the investors are entitled to a definite rate on their investment with a fixed price for their product to the consumer. Every decrease in price, as for example 5 cents per unit in the case of gas at Boston, entitles the investors to an increase of one per cent. in their rate of dividend. An objection to this plan is that while it may be perfectly fair for a term of years, improvements in methods of manufacturing may so largely reduce the manufacturing costs as to entitle the investors to abnormally large dividends, at which time a readjustment of the base for price of product and rate of dividend would result in seriously depreciating the securities held by the owner at the time of such adjustment. This London scale, however, is at present the best practical method evolved for automatically adjusting profits as between the public and the corporation.

Franchise valuations. In considering the expenses and profits of a public-service plant, the engineer must determine the proportion of earnings to be applied to taxes and dividends, the amount of both of which will usually be affected by the value of the company's franchise. At present the franchises of different corporations are variously valued at from less than nothing, or a liability, up to a $20,000,000 asset. Therefore, the competent public corporation engineer must understand what a franchise is, its dollars and cents value and its distinction from the good-will of a going organization, favorable contracts, or physical property.

A franchise is a license, granted by a state or municipality recognizing the right of a public utility corporation to do certain business along prescribed lines. As the privileges and earning power of franchises vary, so their values vary. On one extreme it has been argued that because a franchise costs nothing, or is supposed to cost nothing, it should not be valued or capitalized by a corporation—the present New York statutes prohibit capitalization of franchises by new corporations—because then the public is forced to pay, by increased cost of service, the fixed charges on what they have themselves once owned and gratuitously bestowed. The corporation replies that its franchise is regularly and heavily taxed. If it has no value, it cannot fairly or logically be a subject for taxation; if it has value, it can and should be capitalized. The answer made to this is that the franchise tax is included among the items which go to make up the proper selling price of the corporation's product, and therefore is indirectly paid by the customer without in any way affecting the stockholders' investment or profit.

On the other hand, as the engineer well knows, franchises are frequently granted as a sort of bonus to induce capital to undertake, perhaps at a loss at the start, certain operations for the benefit of itself and the public. One purpose in accepting such obligations has been, not immediate return, but the profits to be gained in the future by the growth of the town or state and the consequent increase in revenue. As time goes on, the value of the franchise increases the same as real estate, or a desirable business location, and it would seem might be just as logically recognized as of value and capitalized.

Granted that certain franchises have becom enormo sly valuable, corporations should not be disparaged on that account. If the public gave away something for nothing, they did so because they were unable to secure any price for it, or they failed to recognize its value and made a poor bargain, or their officers betrayed their trust. Under any of these suppositions the corporations may stand blameless, and are perfectly entitled to their franchises and the value of them. It is but a few years since it was impossible to interest capital in the construction of the New York City Subway; finally, privileges were offered as an inducement and the construction completed, which has proved a notable financial success. Should any one now claim that because the investors have profited largely the contract should be annulled? Yet a few weeks ago the startling doctrine was advanced by a public service commissioner that we of to-day are not bound by an agreement of yesterday, that:

> A common council or a legislature may barter away any present rights, yours or mine, for to-day. But the future is not theirs to give. They may not dispose of rights which belong to our children as much as to us, and to their children and their children's children after them. They may allow private development and management for the sake of immediate public advantage, any such investment must be scrupulously protected; but the franchise itself is something which may not be given away because it is not within the province of the Legislature to give away that which does not belong to the existing community.
>
> A franchise granted by the legislature of fifty years ago belonged then to us of to-day quite as much, if not more, than to our grandfathers, who handed it over to some railroad in perpetuity. It belongs to us now, as it will belong to our grandchildren in their turn. The action of the legislature of two generations ago in giving away our birthright is not morally a binding contract upon us to-day when it comes in conflict with present or future public interests, and the vested rights of the private inheritors of that franchise will not stand when they come in conflict with the vested rights of the whole people of the State of New York.
>
> This may not be 'good law' now, but I believe it will be in a very short time, for the public perception has grown very swiftly of late. And the courts of law are never very far behind public opinion. Some legal way will always be found sooner or later to do what is morally right.

If the commissioner is correct the engineer must know it, and figure a large annual depreciation on the value of franchises; he must ask when does the last generation's rights end and to-day's begin; on what day after granting does the legislature's perpetual grant cease, is it to-morrow or day-after-to-morrow, or next week, or when? Doubtless the commissioner is influenced by the trend of both public opinion and some recent court decisions emphasizing the right of public necessity as against individual or corporate welfare. Perhaps he is overwrought by intimate contact with the oppression resulting from certain grants; but, however rapidly we may have grown in socialistic doctrine, the engineer cannot agree that obligations can be broken simply because they are onerous. He recognizes that the franchise granted 50 years ago had neither the opportunities nor responsibilities of that same franchise to-day. New conditions beget new obligations, which the corporation must meet or the franchise may become valueless on its hands.

Aside from feeling or argument in the matter, the courts have held, and will doubtless always hold, unless it is expressly excepted, that a franchise is property and a more or less valuable asset. If, then, the franchise is property, what may be the value of the property? The present secretive, uncertain, inequitable, unscientific method of arriving at the value of each corporation's franchise, as practised by the State of New York, for example, is, to use the language of the courts themselves, " little more than a guess " and should be replaced by something simple, logical, uniform, and publicly determinable.

It may be right to prohibit the capitalization of future franchises beyond what they have legitimately cost, but the engineer interested in seeing a " square deal " should oppose any attempt to destroy by fiat legislation the value of franchises already established. In many cases there can be no objection to letting the corporations evaluate their own franchises, because the necessity of offering their product at a reasonable selling price on one hand, and, on the other hand, meeting the taxes that may be imposed by the public, will, in the end, generally establish a fair value for a given franchise. Where state commissions have been appointed with large powers to control and regulate public utility corporations, it will be necessary for them to determine a value for the franchises of the various companies under their supervision. Thus far, no logical or uniform method of evaluating franchises has been determined upon by tax assessors, the corporations themselves, the public utility commissions, or the courts.

The more common method of evaluating a franchise that has prevailed, especially among those interested in owning and selling corporation securities; namely, considering the franchise as worth the difference between the value of the physical property of a corporation, and the market value of its stock and bonds, can hardly be considered tenable, for the following reasons:

1. Because in such valuations is included not only the franchise value but also the worth of good-will, favorable contracts, business organization, etc.

2. Because the daily fluctuating price of stock and bonds due to general business conditions, market manipulations, or stock jobbery, make it, as a practical matter, extremely difficult to determine the fair market value of a corporation's outstanding stock and bonds.

3. Because the market value, even if correctly determined, does not indicate, in many cases, the real value of a corporation's stock and bonds. The market value of said securities often depends upon the success with which printer's ink and promoters' efforts have succeeded in impressing the mind of the public, which is generally ignorant, intentionally or carelessly, of actual operating and financial conditions.

The wide difference of opinion among the courts, and the general uncertainty as to the proper method of setting about fixing franchise valuations, is illustrated by the contradictory conclusions reached by the two different officers of the courts who have attempted to place a value on the franchises of the gas companies operating in New York City. The Master who conducted an exhaustive hearing in the matter decided that the franchises were worth $20,000,000. Judge Hough, of the United States Circuit Court, who reviewed the Master's report, concluded that the same franchises were worth $12,000,000. Certainly there should be some fair method evolved for more closely approximating the real value of a given franchise than the wide divergence indicated by these figures. The rule of law under which this country operates is not based on an opinion, guess, or the discretionary rule of an individual, even though clothed with governmental authority. The action of courts, assessors, or commissioners, must be restricted as far as possible to forming conclusions based on definite and fixed laws. It would seem as if the engineering profession, as a disinterested party, appreciating the necessity for and relation of a franchise to a corporation's business, might assist in evolving some method of fairly and logically fixing franchise valuations. The following is suggested with that thought in mind.

Starting with the premise that on one hand the investor in electric and gas utility securities has been demanding a return of from 9 per cent. to 15 per cent. on the actual investment, as shown by the testimony in the Consolidated Gas case from such witnesses as Messrs. Emerson McMillin, N. W. Halsey, Samuel R. Bertron, Allan B. Forbes, " bankers having much experience with gas properties in their investments ", and on the other hand that the courts, as indicated for example in the Consolidated Gas case and the Columbus decision, are inclined to base their decision of " fair return " upon the investment, upon the legal rate, which varies from 5 per cent. to 8 per cent. in different states, we have the extremes of earnings considered fair; namely, from 5 per cent. to 15 per cent. on the actual investment, depending upon location.

For purposes of discussion herein, consider a corporation operating in the state of New York, where the legal rate which, at least, will be allowed by the courts as a "fair return" is 6 per cent. In view of the fact that the capitalist has indicated that he will not be interested at 6 per cent., but that perhaps 9 per cent. would be attractive, are we not safe in assuming that with a New York corporation he would be content with 8 per cent. when he knows that his property will be defended from unfair taxes and competition through protection afforded by a state commission? The nature of the business, compared with other enterprises, is such that the return of 8 per cent. upon the investment actually made by a public utility corporation would not seem unreasonable. Now if the capitalist will accept 8 per cent., and the court will stand by the legal rate of 6 per cent., we have only to prove that the value of the franchise—which the courts have uniformly admitted should be considered as of value—is worth one-third the amount of the actual investment to secure an allowance of 6 per cent. on the whole, or 8 per cent. on the actual cash investment.

An examination of the values placed on many franchises in the past for purposes of taxation, capitalization, condemnation, or court decision, will indicate that perhaps an average valuation of the franchise in each case is not far from one-third of the actual replacement value of the corporations assets. This ratio, though somewhat arbitrarily assumed, would seem under present circumstances to be both a fair and reasonable one for existing franchises. If it is a middle ground on which the various conflicting interests could meet, we will have an automatic, easily determinable, open and above-board method of evaluating franchises. As will be recognized, the proposed method gives a different value to the franchises of different companies, but is equally fair to all because based on their tangible value: it will also be seen that the value of the franchise of a given company may vary from year to year, depending upon the value of their property. Both of these variables are essential in a franchise valuation.

Example illustrating "fair return" for New York corporation.

Life of franchise	20 years	Perpetual
Cash investment or replacement value	$300,000	$600,000
Capitalization of franchise at 33%	100,000	200,000
Total capitalization	$400,000	$800,000
All operating expenses, 40%-50% gross	36,000	96,000
Maintenance and repairs, 7% on 66% investment	14,000	28,000
Depreciation fund, 5% on 66% investment	10,000	20,000
Amortization on franchise value, 5%	5,000	......
Interest on total capitalization, 6%	24,000	48,000
Gross income	$89,000	$192,000

In making up the annual operating and fixed charges of a corporation, it is proposed that the state commission should consider the value of the franchise, as determined above, allowing the legal rate thereon and also a further amount for depreciation or amortization, depending upon the life of the franchise. This latter figure, in the case of a perpetual franchise, would be nothing; but in the case of a short-time franchise would be a very appreciable amount, which of course must be paid by the public. The economy of a perpetual franchise, which the companies desire, will be appreciated, and there is no great objection to it, provided its owner is properly restricted so as to safeguard the public interest. To illustrate the foregoing, let us consider a concrete example of a New York corporation which has been granted a liberal franchise for a period of twenty years, and has invested $300,000 in order to establish a going business, compared with a similar corporation having a perpetual franchise and an investment of $600,000 For more fully illustrating conditions as found, we will assume that the general operating expenses, in the first case are 40 per cent. of the gross income, and in the second case, 50 per cent. due to differences in apparatus installed and efficiency of management. Repairs and maintenance will be taken at 7 per cent. and depreciation at 5 per cent.

If the gross income exceeded the above figures, the price of the corporation's product should be reduced proportionately to a prearranged increase in dividends, in accordance with the London scale or a modification thereof. If the gross income were less than the above, it would be proper to increase the price of the commodity, as was authorized, for example, by the Wisconsin Public Utilities Commission in the case of the LaCrosse Gas and Electric Company.

It will be noticed from the above example, that in a different state with a different legal rate the returns allowed on the investment, and consequently the gross income allowed, would be different. This is as it should be, because the rate of return varies in different parts of the country, as is recognized by the various legal rates in the different states.

The plan suggested for regulating corporations does not place all the corporations on exactly the same basis at the start, as indicated by the example given, due to difference in efficiency of apparatus or management; but these differences are probably not greater than those which arise by reason of location, business opportunity, or public sentiment, and will doubtless about offset one another independently of the fact that the effect of the London scale properly applied has a tendency to bring all companies to the same earning basis.

If some definite plan for determining " fair return " in connection with franchise valuation, could be agreed upon and urged by any considerable proportion of disinterested people conversant with the facts, or even the corporations themselves, would not the commissions and the courts be inclined to accept and adopt such precedent thus established? The result would be a definite knowledge of what returns from public utility corporation investments could be counted upon, and what valuations would be accorded their tangible and intangible property, ignorance of which facts is the principal reason for the present unsettling of their business, undervaluating of their securities, and to some extent the discrediting of the work of the engineer.

Discussion on "The Engineer's Activity in Public Affairs —Public Utility Commissions and Franchise Valuations." New York, April 10, 1908

George S. Coleman: In one respect I agree with Mr. Floy, engineers as a class are, perhaps, a little too modest; but I do not quite agree that engineers ought to be considered in any wise responsible for matters which are hard enough for other men to handle, men who are devoting all their time to it. I do think, however, that the time has come when groups of engineers, different kinds of engineers, should give the benefit of their concerted thought and action to any public question on which they are supposed to be especially well informed. In the case of a new bridge across any of our rivers, or a new subway, or a new elevated railroad, in fact any kind of engineering work likely to affect the public, this Institute, and every body of engineers who in any way might be related to that enterprise, should be heard officially. If Mr. Floy's suggestion this evening shall encourage among engineers the habit of not merely quiet, independent thought in their work, but concerted action after discussion, he will have accomplished a notable result.

I do not quite agree with Mr. Floy as to the constitution of public service commissions. In a country like this, where we are dealing, or called upon to deal, with a body brought into existence through the legislature, and representing the legislature as a sort of permanent committee, what is wanted is men who are intelligent, who are open-minded, who have had some experience in affairs, who are patient, who are thorough, who are industrious, and who have good judgment. Now, I would just as lief commit the affairs of the public service to a body of engineers as to any other body of men whose profession compels them to think, and whose training and experience tends to make them impartial. About three-fifths of the average legislative body are lawyers: that happens to be the present proportion on the public service commission for this district. It has been said that the difference between the common law and the statute law is that the common law is the perfection of reason and the statute law is made by the legislature; this is a legislative enactment and legislative enactments will have to be submitted to until a better law can be framed But I do not agree with Mr. Floy as to the necessity of having experts as members of the commission. To follow that line consistently there would be needed as commissioners not only railroad men, gas and electrical experts, but expert accountants, expert financiers, experts on labor, and on every other subject that necessarily comes before the commission. Depend upon it, if there are three lawyers, or any number of lawyers on any commission, no agreement will be reached without discussion. With three engineers the same might be true, but I do not know from experience. I am willing to leave the composition of the commission to any body of intelligent men who have the necessary qualifications.

On the subject of what a commission should do, I must again differ from Mr. Floy. He cites with approval a quotation to the effect that where *operation* begins *regulation* should stop. If that were taken literally, after the commission has given an order to one of the transit companies to do certain things, like vestibuling cars, keeping cars in better condition, running more cars, or making more stops, regulation would be ineffective if it ceased where operation began. The commission for the first district employs a large body of competent engineers, the eyes, you might say, of the commission, a body of engineers of whom all engineers should be justly proud—men doing their duty well and faithfully, and without prejudice. These men report to the commission what they find and suggest what in their judgment would improve the operation of any public utility corporation. Their reports are submitted in condensed and accurate form, and if the commission may act of its own motion it will, after due consideration, act promptly. If any matter requires regulation, an order will be issued accordingly; if it does not, the matter will be dismissed. Although these things do not always appear in the newspapers, there are many improvements made by many public service commissions which are the direct result of suggestions of citizens or of the inspectors of the board of engineers connected with the commission itself. If the regulation is to be at all effective, details must be carefully considered.

As to the value of franchises, that is still an unsettled question. I sometimes think that the mechanism in the heads of the judges and lawyers and experts has stopped on a dead centre: it is going to require some little pushing one way or the other to bring to an end the question as to the proper way of valuing franchises. We have had some recent experiences in trying to value franchises for the purpose of taxation, and it is not an easy matter. Reputable men will be found who differ honestly as to the proper way of valuing franchises. In three different cases, tried one after another, involving different points, a practically different result was reached in each instance. We have as yet no final decision by our courts. It does not follow because a corporation has invested many millions in plants which have been superseded or duplicated or thrown aside and new plants substituted, that it should earn necessarily a fair return on all its investments. Even the Supreme Court of the United States does not approve of that theory. There is a vast amount of what is known as "lost capital" that cannot be recovered. If Mr. Floy's proposition, with which I agree, is sound, that a corporation already in existence should be treated the same as a new corporation entering the same field, then, of course, as an inevitable result, all the capital expended and taken out has been lost, unless possibly it has produced a *good will*, which, with respect either to a gas company or to some railroad companies, is almost a contradiction in terms. In this city, for instance, there is a railroad company having an excellent franchise. Originally, it was constructed as a horse railroad and operated as such for many years, and then turned into a cable road, and then, not long after, all the cable apparatus was removed and it was turned into an electric road. In 1900, when the Special Franchise Act came into effect here, there had been $26,000,000 represented by capital stock, $35,000,000 represented by bonds, and some floating indebtedness outstanding, and yet according to the appraisements made by the company itself, the total plant—tracks. roadbed, power house, and electrical apparatus—could be duplicated for about $10,000,000. There was a frightful waste, apparently and actually, of good money which never could be made up, unless that company should be treated differently from a new company starting with $10,000,000 capital and a similar franchise. Let us be thankful that we do not have to decide that question to-night.

The other suggestion in connection with the subject of the franchise was, that if a corporation should be restricted to earning what is called a fair return on its capital, and every corporation is treated on the same basis, improvements may be discouraged. But the modern theory seems to be that where there is state regulation a monopoly is not dangerous. It might well happen that one great gas company, one great electric company, one great transportation company, in the Borough of Manhattan, would be sufficient and would not be objectionable if it were wisely regulated. That would do away with one objection of Mr. Floy's resulting from competition, or lack of competition, if all corporations were to be treated alike.

A friend of mine, a lawyer, said to-day: "I sometimes wish very much that I could go out and deal with *things*, instead of with *ideas*." The more one deals with ideas, except as those ideas are related to practical things, the more at sea one becomes. I agree with Mr. Floy that engineers have been too modest, but in other respects I have to differ with him.

Chas. F. Lacombe: In discussing Mr. Floy's paper possibly more value will attach to these remarks if it is stated that my past experience has been largely in the line of building, operating, and managing lighting and power plants, and that in entering the city's service it was entirely from a non-political standpoint, my work being purely of a professional character. During the last five years in the city's service a number of important discussions have come up, in which my particular work was involved, and, in consequence, I have been in close touch in these matters as they have occurred.

In discussing this paper, one may assume probably that public supervision of public utilities corporations by commissions or other bodies is necessary and has come to stay, not on the theory that all corporations are bad or that even a majority are bad, but on the theory as shown by experience in late years, that wise and far-seeing regulation of public service is necessary to prevent the sacrifice of the service later on to the demands of that portion of the financial world which apparently requires great profits from stock speculation to the detriment of everything else. The present New York street railway situation is a shining example of this, as well as of a law as to transfers that is almost disastrous.

It has been said that the public gets no better service where there is public supervision, than it does where there is no supervision: that is a question that depends largely on the kind of control exercised. We will also need time to improve and perfect a method we have only just begun to use. This criticism may be true in a limited sense where the companies are working on a high plane, not only for the benefit of their stockholders, but for good service to the public. But the idea that there should be no public supervision because there are many of these companies, if carried to the limit, could be compared with the fact that we pass laws against crimes, not because the great majority are criminals, but to protect that majority against the very few who are.

It is also the duty of a public service commission to stand between the company and the public when the public demands are unfair or impossible. Some of the most difficult work the engineer has to do in public service is to prevent demands being made, mainly from ignorance, which are impossible to fulfil. It is our duty at times to protect the public against itself. This may sound odd, but a very good example is the present police traffic regulations.

From personal experience, I thoroughly approve Mr. Floy's contention that there should be some engineering representation on these commissions. Their work certainly comprises supervision of the most important engineering enterprises in the district which they control, and even one well equipped engineer of what we might call "general administrative engineering experience," would be a great aid to the commission in rendering unnecessary, if the term may be used, the conduction of the entire commission through matters of technique, which the engineer could settle at once, thus saving much time for the whole commission and giving them a clearer view of the main point at issue.

In reply to this, in discussing it with attorneys on a friendly basis, they are very apt to say: "Well, assuming that the board is made up with no engineering representation, they can hire engineers." The reverse of this proposition would be equally true, that if it were made up largely of engineers, it could hire representatives of other professions. In a way, business men and other professions seem to regard the engineer in the light of an expert only, in a limited field, and that beyond this he has had little experience and has little knowledge of the affairs of the world at large with which they think they are more closely in touch. It is hardly necessary here to point out the large number of what might be termed "administrative" engineers, actively engaged in managing, at least in part, not only the engineering side but the business side of a great number of the enterprises.

The engineer advising a commission of non-engineers not being a member of the body, would certainly be compelled to exercise the greatest care and conservatism in expressing opinions, which might be misconstrued in discussion among men who were not engineers. Nor would such an engineer take the responsibility which he might take as a member of the commission. This fact, in my experience, has been noted a number of times. The salaries offered by the State for engineers serving the commission, but not members, would not attract the men that could be secured as commissioners by the honor and dignity of the position. A commission dealing largely with engineering subjects, therefore, made with a proper representation of lawyers, engineers, and business men would, I think, be of more value than one in which either element was left out.

From lack of careful engineering consideration due to hurry and rush caused by public clamor, regulations have been passed by commissions and by the legislature itself, which could well be termed "inexpert legislation," and which the courts have rejected. This appears entirely unnecessary, and involves a waste of large sums of money. Much time and trouble would be saved in long and expensive lawsuits which have come from just this form of error. If an experienced, conservative engineer, with the power he would have as a member of such a commission, had been in touch with the matter he could probably have prevented a number of such cases in the past, for public clamor and government by newspapers would naturally not appeal to him as against his knowledge of the laws of nature. In support of this, I would call attention to an example of inexpert legislation, of which we have heard a good deal.

This is the suit of the Consolidated Gas Company against the attorney general, the district attorney, and the New York State Commission of Gas and so on, and also the City of New York, as contesting the constitutionality of Chapter 736 of the Laws of 1905, and Chapter 125 of the Laws of 1906, this latter law being known as "The 80-Cent Gas Act."

The Gas Commission set the price of gas to the private consumer at 80 cents in the city of New York, and the price of gas to the city for its own purposes, at 75 cents per 1000 cu. ft. A decision has now been rendered against the city by the United States Circuit Court, Southern District of New York, which will be appealed to the Supreme Court of the United States, for the settlement of certain points as to constitutionality. A great deal of pressure, as voiced by the newspapers, was brought to bear on the commission. If the commission had had an engineering representative of high standing it is probable that, taking into consideration the success of the sliding scale for gas companies in England, some such sliding scale would have been adopted here, instead of making a direct cut from $1.00 to 80 cents, and to 75 cents in the case of the city itself. This reduction might have been extended over a period of years, so that the increased consumption of gas, which seems inevitably to result from a decrease in price, would have convinced the companies that they would not be taking the risk of having to operate at a loss.

There is also in this law the requirement that gas shall be supplied at a pressure of not less than one inch, and not more than two and one-half inches in *any service main at any distance* from the place of manufacture. As a matter of fact, to-day modern gas appliances require really a higher pressure than the minimum set, and the city itself in requiring the operation of gas lamps is put in a peculiar position, in that it is forced to require a minimum pressure of one and one-half inches in order to operate the mantle lamps at reasonable efficiency, whereas the legislative act allows the company to fall to one inch pressure before the company is penalized. In Manhattan, with the very considerable rise in grade between the lowest point and the highest point, the rise in pressure due to the height of the column of gas will alone force the gas pressure beyond the legal limits. The Consolidated Gas Company tried to operate within the legal limit, and they found that when they did they received a large number of complaints from people who could not operate their gas stoves and cook their meals on account of low pressure. The penalty for any violation of this condition was $1,000 for each offense. It has escaped my mind now as to how many times the companies were found above or below the pressure required, but the last time it was looked up, and that was a year ago, the penalties would have amounted to a very large sum.

The candle-power of the gas was also raised from 20 to 22, which seems unnecessary, and if the gas fell below this candle-power, the company was to be penalized by a fine of $1,000 for each offense. This also added materially to the cost of making gas.

Further than this, in the same law—Chapter 736 of the Laws of 1905—the companies were also penalized $1000 per offense in case they even sent a bill to the City of New York for over 75 cents per 1000 cu. ft. I cannot tell you the figure to which these fines would reach in case they had all been enforced rigidly and an attempt made to collect them.

The United States Circuit Court in its final order declares that all these penalites are unconstitutional and void, and are not to be enforced. More than two years' very hard work was put in by both sides in this case, and the joint expenses of the city and the company will amount to a large sum. Meanwhile the people of the city of New York have received little if any benefit. I think I can say safely that if it had been left to a board having one or more competent gas engineers as members, these errors might have been avoided, and the price to the consumer gradually reduced.

In addition to these matters, caused by inexpert legislation, the Supreme Court of the United States has recently rendered a decision in what is known as "The Minnesota Case," in which they state that the laws as passed by the legislature in the State of Minnesota affecting railroads and warehouses, contain certain penalty clauses which would act to prevent the railroads and warehouses from going into court at all, and, in consequence, these penalites are unconstitutional and void. Beyond that they refer the matter back to some other court as to the propriety of the rates involved, in the following language:

It cannot be to the real interest of any one to injure or cripple the resources of the railroads of the country, because the prosperity of both the railroads and the country is most intimately connected. The question of sufficiency of rates is important and controlling, being of a judicial nature it ought to be settled at the earliest moment by some court, and when a Federal Court first obtains jurisdiction, it ought, on general principles of jurisprudence, be permitted to finish the inquiry and make a conclusive judgment, to the exclusion of all other courts. This is all that is claimed, and this, we think, must be admitted.

It is apparent, therefore, that penalties which are not legal and reasonable will be considered very carefully by the courts in these matters. While the Consolidated Gas case does not show any clauses preventing the company from having its day in court, it does show penalties imposed on the disobedience of conditions which are impossible or unreasonable. One, if not two, of these conditions would have been condemned by engineers.

Decisions of this character certainly point out that legislation affecting public service corporations must be fair and reasonable, and should be made by men who know something of the engineering and operating conditions. They point out forcibly the necessity and propriety of having a skilled and experienced engineering member in a public service commission.

Mr. Floy also takes up the interesting question of franchises, what they are and what their valuation should be. To bring this matter up to date, I have procured and will read to you some definitions given of a franchise in the last decisions of the United States Circuit Court in the Consolidated Gas Case, as rendered by Judge Hough, and also as to the valuation of the Consolidated Gas Company's franchise.

It appears that, apparently, the question as to whether a public service corporation is entitled to add the value of its franchise to the tangible assets on which a fair return would be lawfully demanded, is to be submitted to the Supreme Court of the United States for the first time. The United States

Circuit Court points out that the investment of property in a manufacturing plant was made, not *in* the franchise, but *under* the franchise, and on the faith thereof. In speaking of the ways in which the value of a franchise can be stated, the court says, speaking probably of the usual methods of obtaining franchises:

On every private sale of franchise property, the price paid is so much money lost to the public by official incompetence or worse, and such sale can confer on the vendee no right to compel the consumer to repay him a price which should have been paid to the State. For these reasons I believe that, on principle, the franchise should be held to have no value except that arising from its use as a shield to protect those investing their property upon the faith thereof, and that considered alone and apart from the property which it renders fruitful, it possesses no more economical value for the investor than does the actual shield possess practical value apart from the soldier who bears it.

The court then states that many decisions have been rendered, the trend of which is against his own views, but that for good reasons he must follow the weight of authority. He says:

I conclude, therefore, that I am compelled to consider franchises not only as property, but as productive and inherently valuable property, and to add their value, if ascertainable, to the complainant's capital account before declaring the rate of return permitted complainant by the statute complained of.

In a later decision, after the re-opening of the case for certain reasons, speaking of his valuation of the franchise, the court says:

It is not difficult to detect flaws in findings opposed to the settled opinions of the judge who happens to constitute the court.

The court in its first decision then goes on to the question of valuing franchises, and says that, for the purpose of condemnation or regulation:

The value of the franchise depends wholly upon what is earned under it, and I believe the best way of finding out how much a franchise separately considered is worth, is to ascertain what those persons desirous of continuing operations under it consider it to be worth. In a corporation whose stock is freely bought and sold, such value is measured by the success attending the sale of stock based entirely upon capitalization of franchise, yet the value of stock issued only in consideration of the franchise is obviously dependent on earnings after the stock based on tangible property has received a satisfactory dividend.

This is really the same measure of value that the New York Franchise Tax Commissions are using, except that instead of that reasonable return upon the tangible assets deemed by the commission as sufficient, there is substituted the opinion of the investing or speculative public as to what constitutes a satisfactory rate or return upon all stock. Thus, if the investment of a hundred thousand dollars in a franchise protected business authorized, in the opinion of the promoters, the issue of two hundred thousand dollars' worth of stock, and such stock for a number of years maintains itself at par, paying satisfactory dividends, it would be obviously fair to assert that in the opinion of the share-holders that franchise is worth one hundred thousand dollars, assuming no depreciation of tangible assets. Yet it will always be true that unless the whole net return, compared with the value of tangible property, is above a satisfactory return on the tangible investment alone, the addition of stock issued for franchise will be regarded as "water", and detract from the value of the entire issue, and I think this is conclusive proof that value in a franchise depends wholly on what the actual investment can earn.

I consider the real reason which compels me to consider the value of franchises to be that for generations it has been the universal practice of American Corporations, supported by the opinions of courts and counsel to capitalize their franchises for all it was thought traffic or business would bear, until the country is full of share-holders whose certificates of stock are based upon the belief that in some way or other such certificates were legally created pieces of property and would, like other property be protected by Federal and State constitutions.

The court then goes on to value the franchise at this date on the basis of the valuation in 1884, when the Consolidated Gas Company was started, proportioned to the value of personality and realty of thirty million dollars, the investment at that time in tangible assets. He finds the investment in tangible assets in 1905 is forty-seven million dollars, and the franchise valuation proportioned thereto would be twelve millions, which he allows. The court explains this in his later opinion, in which he states that the franchises of 1884:

Might as well have been valued at twice the amount of stock then issued. It was nothing but an attempt to capitalize expected profits; but the attempt now has twenty years' success to justify it.

Further on he defines franchises as follows:

The so-called franchises may be denominated "licenses, or tenancies at will" or "continuing trespasses", yet what is being done under them is a fact, a profitable thing, a taxable property by the law of this state, The State of New York, therefore, is estopped from continuing to tax that property by one set of representatives and denying it all value through the instrumentality of another.

The contention of the city of New York in this matter was that the franchise had value as regards condemnation or sale, but that it should not have value when it capitalized that value and charged a return upon it against the public that gave them the franchise.

It will be very interesting to note the decision when it is given by the Supreme Court of the United States, and it is to be hoped that it will go into the question of what is the proper way to value a franchise, particularly when, as stated, this has come before the court practically for the first time, strange as that may appear.

I trust that I have not quoted too much law, but I thought that it would be of service to bring in some of the decisions which have been rendered since Mr. Floy wrote his paper, and I also thought that it might be of value to a number of engineers who are at times confronted with similar problems.

H. M. Brinckerhoff: This question of the necessity of co-operation between corporation officials and the public service commission was made a prominent part of the speech of Commissioner James E. Sague, of the Second District of the State of New York, at the annual banquet of the Stevens Alumni Association. He said:

Satisfactory results can only be obtained by cordial co-operation between the corporation officers and the commissioners in the same spirit which was exercised in the conference between the Interstate Commerce

Commission and the corporation accountants in the preparation of the uniform system of railway accounts recently adopted. . . .

In all departments of the commission's work the same necessity for co-operation is apparent. We all need to be educated in this field. We can probably learn much from Europe, and especially from England, where the Board of Trade has functions similar to those of our commissions. The commissions need all of the intelligent advice that they can get, and all criticisms if kindly made, will be received in an humble spirit. We want to know where to begin in our work. We want to learn what is most important to be done now, and what ought to be left for the future, and we need especially perhaps to learn where to stop.

This is the carefully considered, positive statement of the only technical member of the New York State Public Service Commission, and when it is considered that Mr. Sague has had long experience in railroad operation as well as large corporation affairs, it forms a very striking argument for exactly the idea we are advocating.

Our public utility boards and railroad commissions to attain full usefulness should have upon them some experienced men, men who have been through the mill and who will not ask the impossible. No man, no matter how sincere and devoted, can grasp in a few minutes, operating questions with which he has never had actual personal experience.

The great variety and complexity of questions coming before public regulating boards require for proper balance a membership representing legal, financial, and commercial experience, but equally important is it that some experienced operating members should sit upon these boards in order that a proper appreciation of the effect of proposed orders and regulations may be considered and clearly appreciated by the board during its deliberations.

At this point I part company with the author in that I do not agree with his contention that commissioners should be primarily and exclusively engineers, and I doubt whether this was in the mind of Mr. Perkins when he made the remark:

A Railroad Commission should be composed of railroad men who can deal with the questions arising in a practical way.

The questions which come before boards of public control are 90 per cent. operating questions in the sense that they affect directly or indirectly the methods of, quality of, or remuneration for, operation. I have no fear that legislation or the rulings of utility boards will reverse the laws of gravity, strength of materials, or even the design of rail-sections; but I do fear that their action in certain instances will have an unexpected detrimental effect upon the very service which they were hoping to improve, a result which experienced operating men would clearly foresee.

Purely engineering questions should be handled by engineering experts who are making a specialty of the particular line momentarily under consideration. Mr. Floy's remark in regard to hired experts seems to be a condemnation of all consulting engineering work, as there should be no difference in the amount of responsibility assumed or service rendered when acting for a public commission, a corporation, or a private individual. No one engineer-member of a commission could expect to keep up with the vast intricacies of all the engineering questions which might come before the board, whereas a practical, experienced operating man who had had the daily, monthly, and yearly running of a plant or system under his charge, would have sufficiently good judgment and experience in engineering matters to know when he must call upon an expert engineer and properly to select such an expert.

There can be no question that in many instances where public service commissions make rulings adverse to the company, which afterwards prove unwise, it is quite as much the fault of the company as of the commission, the company not having fully laid before the commission the actual facts in the case. In this connection the attitude taken necessarily, or perhaps we might say customarily, of presenting matters to a commission in public meeting as they would be presented before a criminal court, brings about an unfortunate result.

It is probably impracticable at the present time to expect matters of this kind to be considered openly in a fair, candid discussion, but if such a course could be pursued I am satisfied much better results would be obtained than by the formal, legal methods now pursued. Our commissions would very seldom go radically wrong if they had the real facts placed clearly before them. Two conflicting, cleverly concocted, partisan statements, on the contrary, befog rather than clarify the issue.

Every operating man knows that to make the worst appear the better reason, while it may be a triumph of legal skill, is not a satisfactory method of deciding operating questions. There may be differences of judgment, but an accurate basis of facts is necessary for the protection of both parties to a controversy. A short cut to a correct result would in many cases often be made by the presence on the board, as has been suggested, of experienced operating men, and I am greatly in hopes that we will see before long the appointive power fearlessly used to place upon these commissions carefully selected men of this class to coöperate with and assist the otherwise excellent personnel of which the commissions are composed. Such appointments would not only be just to the railroads but beneficial in the long run to the public.

Louis A. Ferguson: I heartily concur with Mr. Floy's views as to the desirability of having thoroughly trained and well equipped men of technical knowledge and broad experience upon the various commissions entrusted with the duty of regulating rates or the conduct of business by public utility corporations. It appears to be the trend of modern legislation to take from the various legislative bodies, city councils, etc., the power of regulation of public service corporations, and place it in the hands of commissions. This is extremely desirable, not only from the viewpoint of the corporations, but of the public as well. Attempted regulation of public utility corporations by large, unwieldy governing bodies such as the board of aldermen of large cities like New York, Chicago, Philadelphia, or Boston, is seldom satisfactory either to the corporation or the public. Such bodies rarely number among their members men of sufficient technical knowledge and training to enable them to pass upon the questions involved with any degree of satisfaction. For instance, when the regulation of the rates to be charged by a telephone company, a gas company, or an electric lighting company comes before a body of men numbering from fifty to seventy, it is almost impossible sufficiently to educate so great a number of men in any reasonable period of time so as to enable them to pass intelligently upon the questions involved. Usually many months, and often years, are spent in hearings before such bodies, and finally a rate is established which is not infrequently but a compromise between the rates proposed by corporation and the board of aldermen; it is not a rate based upon a thorough, scientific basis of reasoning. During all this time the affairs of the corporation are in a disturbed condition, its directors cannot plan any extension of business, the proper financing is made much more difficult, and stockholders become alarmed at the various reports as to the probable action in regard to the fixing of rates. How much more satisfactory and how much fairer is a hearing for such a purpose when conducted before a properly equipped commission appointed either by a legislature or by a governor, a commission numbering say three, five, or seven, all of whom, or at least a majority of whom, are thoroughly trained engineers, possessed of a scientific knowledge of the subject under discussion, and able, of their own knowledge, to arrive at an absolutely fair result, fair both to the corporation and to the public.

Practically everyone will concede that a public utility corporation is entitled to a fair return upon its investment. The chief difficulty encountered is the varying views of different people as to what is meant by " fair return ". Some extremists contend that the legal rate of interest fixed in any state is a fair return for public service corporations doing business in that state, while others contend for as high a rate of interest as capital can secure by engaging in any mercantile or other legitimate enterprise. In my opinion neither of these views is correct. There are but few capitalists that would care to engage in any industrial enterprise, such as manufacturing, where the returns upon the investment would be less than twelve per cent. A review of the returns made upon capital invested in banking enterprises throughout the country shows a very high return of interest upon the capital invested, in many cases running as high as twenty, thirty, fifty, and in one case at least as high as one hundred and twenty per cent. No one will seriously contend that a public service corporation is entitled to so high a return upon its investment as is referred to in the case of banks; nor, on the other hand, should anyone seriously contend that such a corporation is entitled to, say, only five per cent. return upon its investment, five per cent. being the legal rate of interest in the State of Illinois. It is axiomatic that the return upon capital invested in public service corporations should be sufficient to entice capital. There is no magic about a public service corporation or about the business in which such corporations engage which will serve to attract and interest capital, unless the return upon the money invested be approximately that which might be earned upon the money if invested in other legitimate enterprises. It is my opinion that public service corporations would be and should be satisfied with a lower rate of interest upon their investment where their rates and other business dealings with the community are controlled by a commission, small in number and composed of, say, trained engineers, than they would deem satisfactory if their rates and other business dealings were controlled, as they are now, by state legislatures or boards of aldermen. In the first case the corporations may be reasonably sure that no radical measures will be advocated by a commission which would serve to throw unnecessary burdens upon the corporation, or which would prevent the corporation from earning a fair return upon its investment. In the second case the corporation is compelled to exist in a constant state of uncertainty, never knowing what wave of radicalism may strike the community and be reflected in its lawmaking body, whereby public clamor may result in the fixing of rates so low as practically to amount to confiscation, or in the surrounding of the business with such so-called safeguards or other provisions relating to methods of bookkeeping, etc., as to make it, if not extremely difficult, at least extremely expensive to operate its business in a satisfactory way and in compliance with the law.

Too much stress cannot be laid, however, upon the absolute necessity of appointing as members of state commissions entrusted with the regulation of the affairs of public service corporations, men of undoubted integrity, the highest order of ability, and possessing the confidence of the community. In fact, the members of such a commission should be the same class of men, so far as their standing and ability are concerned, as we expect to find in the Supreme Court of the United States. If these commissions are to be made fat berths for politicians, public service corporations have only jumped from the frying-pan into the fire. The temptations and possibilities for wrong-doing in such a position are enormous, and weak or unscrupulous men occupying such positions would have it in their power either greatly to oppress the corporation or so greatly to favor it as to create much dissatisfaction in the community, a state of affairs which would eventually result disastrously to the corporation.

There is no doubt that the sentiment of the public is now undergoing a marked change in its views toward public service corporations. We have passed through an era of radicalism during which the public regarded large public service corporations in the light of public enemies, and believed that no measures were too severe to be directed against the corporation and no restrictions too rigid to be thrown around them. It was formerly thought that competition was the thing, and that by granting a license to several gas companies, several electric lighting companies, or several telephone companies, much better service and much lower rates might be secured. It has been discovered that this theory is entirely wrong, and it is now rapidly becoming the sentiment of the public that the best interest of the public is served by a properly regulated monopoly. It has been discovered that whenever two or more public service corporations engaged in the same line of business are serving the same community, they are not likely to remain separate very long. Duplication of plants is a waste of capital which is not economic, and, if persisted in, necessitates a much greater outlay for cost of operation. If there is *bona fide* competition between two such corporations, it means a war of annihilation until the weaker of the companies is forced out of the field. This militates against good service and also prevents conservative capitalists from investing money in public service corporations doing business in a community where such a state of affairs exists. Where a public service corporation may be assured of a monopoly, or a practical monopoly, of the field, it may very well consent to do business at a much lower rate of interest upon its investment, because the fear of irresponsible competition is removed and the business may be conducted with an exact knowledge of all the factors entering into the cost of conducting and maintaining the corporation and prosecuting its business.

The remarks of Mr. Floy upon the desirability of engineering experts equipping themselves for service upon state commissions and the advisability of the various societies and similar bodies of engineers taking an interest in public affairs with a view to having their members placed upon such commissions, commend themselves to me, and I am a firm believer in the advisability of adopting such a policy on the part of our engineering bodies.

Henry L. Doherty: There is so much to be said both for and against public control of public service corporations that nothing short of a large volume would cover all of the important things which might be considered. Therefore, I shall touch briefly on only one or two points of first importance.

Public opinion is such that perhaps public control of public service corporations is inevitable. It would seem self-evident that the scope of this control should be the least possible to insure protection to the public. The recent tendency of some of the public utility bills, however, seems to anticipate public general managership rather than public control.

The broader the scope of control attempted, the less efficient will be the work of public control; and an attempt at too much breadth will defeat the whole scheme of public control. If public control is inevitable, this control must be shaped so as to make its disadvantages the least burdensome and its advantages the most beneficial. To insure impartial decisions the executors charged with public control should be as far removed as possible from the influence of public opinion.

Public control, however, is apt to convince the owners and managers of a quasi-public corporation that only the minimum returns may be earned and distributed. And this interpretation of public control removes all incentive on the part of the owners and operators of quasi-public corporations to make proper effort for economies and improvements. The so-called "London Sliding Scale"—which is a very incomprehensive name to a very comprehensive subject—is an attempt at a reasonable division between the public and the owners of the property for improved results. For public control to be a success, it must be automatic as far as possible, and the company must be rewarded by higher returns for improved results. The best plan for the accomplishment of this end can, I believe, be secured by, and demands, engineering consideration.

The men charged with this work must have an extraordinary degree of intelligence, or else a combination of experience in the business which they are expected to control coupled with a high degree of intelligence.

These executors are generally constituted as commissions, and they in turn must have a competent staff of accountants, statisticians, and experts. The success of the plan must rest primarily with the fairness and intelligence, not only of the commission itself, but of all their various assistants. Under modern conditions a public service commission cannot do either intelligent or effective work without competent engineering advice or assistance. This I think is generally recognized, and the commissions accordingly have their engineering staffs. But in selecting the commissioners themselves the engineering profession should not be overlooked as a very likely source of the best available timber.

W. W. Freeman: With respect to the question as to what would be the best make-up of the public service commission, I have no suggestions to offer. I have found no difficulty in agreeing with some things that have been said by each of the speakers. As one who does not claim to be an engineer, I entertain no fear whatever from the standpoint of having the engineers represented on the commission. At the same time, I should be equally anxious to have a thorough representation of broad gauge business men who would view the situations presented from the executive and business standpoints, entirely aside from engineering or technical ideas.

I agree with Mr. Floy that the matter of determining the value of a franchise is likely to adjust itself when it has been definitively decided that the valuation admitted for the purpose of taxation is equally available as an asset upon which a fair return can be earned.

In the matter of a fair return, Mr. Floy apparently thinks that six per cent. is admitted from the legal standpoint, that nine per cent. or more is asked for by the investing public, and that eight per cent. would probably be acceptable, and that the franchise should be fixed at a valuation that will make up the difference. If the franchise has a legal valuation the companies are entitled to the return on that valuation, whether it be for property that is intangible or tangible; and it would seem that if we are claiming eight per cent. or any higher per cent., we must of necessity in justice to our own interests ask and demand that return upon the fixed valuation of the franchise the same as on the tangible property.

It seems to me that the plan of fixing the gross income which a company shall be entitled to earn, after its expenses, plus depreciation and plus six per cent. of eight per cent. return, leaves altogether out of consideration the fundamentals on which the business is based. The first consideration in public service regulation doubtless ought to be a demand for good service. I think we will all agree to that.. Then of course comes the demand for a reasonable charge, which is admitted; and then the question of a fair distribution to the stockholders, which is also admitted. But equally important with these three is what amount over these items must of necessity be assured to the company for permanent and successful operation. There are years when the revenue will be less than in other years, and any company that disburses all of its earnings in its good years will have no earnings to disburse in the poor years. The maintenance of a permanent investment requires of necessity some reserve, and in addition there are the expenditures attaching to extension work and improvements. These vary with the company, and the idea of the company earning only the amount which it needs for distribution to its stockholders seems to me to be ill considered. I believe that public control should be exercised over, not so much what the company earns but the amount disbursed, and what it does with the balance. For instance, a company that has a capitalization of $1,000,000 and earns and distributes, say, over and above expenses, eight per cent. on $1,000,000, distributes $80,000 a year, and that company requires $50,000 or $100,000 a year for the extension of its business in new work. Now, whether that company issues additional capital during each year to take care of these extensions, and pays the same rate of dividends upon the total capitalization, or whether it earns a sufficient amount to enable it to pay a fair rate of return to its stockholders, and also a sum beyond that which will enable it to take care of its extensions and additional capital, is the same thing to the public, but it means a great deal of difference to the company. I feel that it would be very much more conservative management, very much more in the interest of both the corporation and the public, if the company should be able to manage its business so that it could take care of reasonable expansion independently of its ability to raise further capital from year to year, so long as it is supervised in respect to its charges and its disbursements, and what it does with the surplus. If that plan were followed, it would be very much in the public interest as well as in the interest of the company.

George S. Coleman (by letter): I should like to add a comment on that part of Mr. Floy's paper in which he says:

> A perusal of the minutes of the hearings held before state commissions will convince any unprejudiced person that a disproportionately large amount of evidence and testimony is submitted, in the consequent unnecessary financial expense and consumption of time for the purpose of explaining terms, apparatus, and methods of operation and expenditure to commissioners who, in general, should be acquainted with the matters being considered.

In justice to commissioners generally it should, perhaps, be said that their official duties require them not only to decide questions but to preserve a record of the testimony submitted, and to make the record intelligible to those who are not experts. In an ordinary suit at law technical terms have to be explained for the benefit of court and jury. The commissioners must fortify their findings by a proper record, so that if their decisions are challenged they may properly defend them. While this involves tedious inquiry it seems almost essential to orderly procedure.

Henry Floy (by letter): It is a pleasant surprise to find so much agreement among the engineers, if not among the lawyers, with the views expressed in my paper. Even Mr. Coleman agrees with my opinions more fully than perhaps he seems to admit, when he says:

> I would just as lief commit the affairs of the public service to a body of engineers as to any other body of men whose profession compels them to think, and whose training and experience tend to make them impartial.

I do not for a moment wish to convey the idea that various engineering specialists, experts in particular departments, should make up a commission. I do not argue that an electrical expert, a specialist, should properly be a member of the commission, or as Mr. Brinckerhoff seems to understand, that "commissioners should be primarily and *exclusively* engineers." I would consider a mechanical engineer, if he knows something of electrical work, hydraulic work, gas work, and has had experience in the operating and commercial departments of a public utility corporation, much better qualified to make a good commissioner. The same way with the railroad man. What is wanted is not an expert designer of cars or locomotives, but an engineer experienced in railroad organization and operation. Mr. Coleman makes the too common mistake, which I referred to, of considering a man with a technical training capable of passing on technical questions only, whereas such training is, frequently, merely the basis for success in commercial and economic affairs. I do not argue that a commission should be made up, entirely, even of widely experienced engineers; that would be as erroneous as constituting it of lawyers or business men. Neither can I see any necessity for three out of five members of a commission being lawyers; for a large amount of the work of a commission has nothing to do with law, as such, while much of it has to do with engineering questions. From my experience before commissions, I believe more helpful and practical results would often be accomplished in a simple and expeditious way by following procedure which might possibly be termed engineering rather than legal. Why questions involving matters of an engineering nature cannot be best answered by a commission constituted partly of men who are conversant with engineering affairs, I cannot understand. My plea is for a balanced commission consisting of engineers, business men, and lawyers.

With regard to operation versus regulation, Mr. Doherty's discussion very completely expresses my view.

Mr. Brinckerhoff's ideas and my own, as to the value and propriety of retaining consulting engineers, are, I believe, identical. My thought was that the responsibility for a decision must rest upon the commissioners; it should not on any plea be shifted by them to "hired experts", however competent, either as consultants or as direct employees.

As I understand Mr. Freeman, it does not seem to me he quite appreciates some of the points I have tried to bring out. There is no getting away from the fact that commissions are being appointed and franchised valuations are being determined. One need not agree that one-third is the correct valuation of a franchise, but some valuation must be fixed; and it seems to me we need to study this question and try to determine the figure that will be reasonable and fair to both sides. Purely as an illustration, I have suggested a franchise valuation of one-third and a rate of six per cent. because in some cases that is a fair valuation and rate; and we may be able in some instances to get the opposing sides to compromise on these figures. Of course, as an Institute we do not want to stand committed to six per cent. or any other per cent., but as a practical proposition it is comparatively easy to get money to invest at eight per cent. if the investing public is assured that it will be protected in an eight per cent. net return. In the past the New York public service corporations may not have been able to get investors interested on an eight per cent. basis, but they will be able to do so in the future if their interests are protected by a commission.

I agree with Mr. Freeman as to the necessity of a reserve account, which, however, together with other similar items, was covered, in my thought, by the percentages allowed for " maintenance " and " depreciation." The amount and itemizing of these several details is, of course, immaterial for the purpose of here illustrating a method of determining franchise valuation. I differ with Mr. Freeman as to his suggestion that a public service corporation should provide for its expansions from earnings; I had supposed it was now pretty generally agreed that extensions should be charged against the capital account instead of being made a part of the charges for service.

A paper presented at a meeting of the Pittsburgh Section of the American Institute of Electrical Engineers, Pittsburgh, Pa., May 6, 1908.

CALCULATION OF THE STARTING TORQUE OF SINGLE-PHASE INDUCTION MOTORS WITH PHASE-SPLITTING STARTING DEVICES

BY I. E. HANSSEN

The starting torque of any induction motor is proportional to the product of the main field by the quadrature field, hence to the product of the main electromotive force by the quadrature electromotive force. The starting torque of a single-phase induction motor with a phase-splitting starting device can, therefore, be predetermined if the electromotive forces at the terminals are known.

If we have a Y-connected motor, we first calculate the starting torque which the motor would develop on a three-phase circuit; in this case the above product is $e^2 \frac{\sqrt{3}}{2}$ and the area of the electromotive force triangle is $e^2 \frac{\sqrt{3}}{4}$, where e is the terminal voltage.

The actual torque of the motor on a three-phase circuit is

$$T_s = \frac{3\, e_0^2\, r_s}{Z^2\, 746}$$

where

e_0 = Impressed electromotive force per phase.

r_s = Secondary resistance per phase reduced to primary terms.

Z = Total impedance per phase.

If the same motor is now connected with a resistance reactance starter as shown in Fig. 1, the electromotive forces at the terminals can be found as follows:

Referring to Fig. 2, lay of OA and OB representing the impedances $Z+Z_2$ and $Z+Z_1$, respectively. Draw a line in the direction OD, the angle BOD being equal to AOC and angle

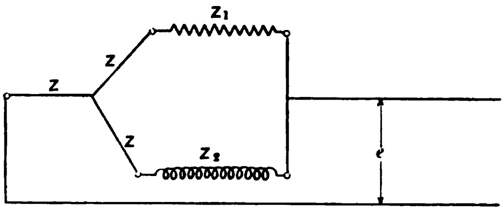


Fig. 1

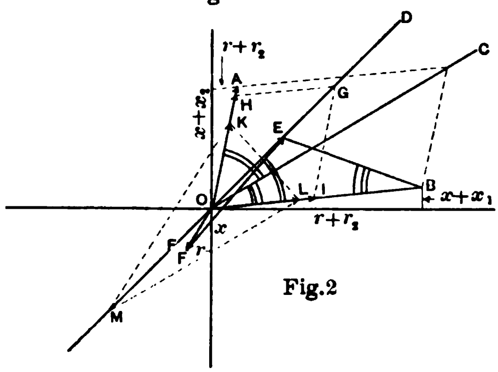


Fig. 2

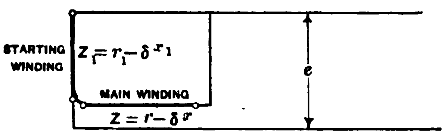


Fig. 3

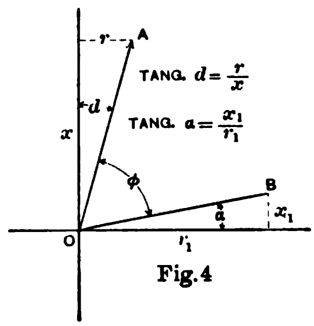


Fig. 4

e = line e.m.f.; r_p = primary resistance per motor phase; r_s = secondary resistance per motor phase reduced to primary; r = total resistance per motor phase reduced to primary; x_p, x_s and x corresponding values of leakage reactance; $Z = r - jx$ = impedance per motor phase; $Z_1 = r_1 - jx_1$ = impedance of one leg of starter; $Z_2 = r_2 - jx_2$ = impedance of other leg of starter.

EBO to the angle BOC, OC being in the direction of the resultant of OA and OB. OE is then the joint impedance of $Z+Z_1$ and $Z+Z_2$.

Draw $O F$ representing the impedance Z. $E F$ is then the resultant impedance of the motor and starter.

Divide this into the line voltage; this gives the total current, which is to be laid off along $O D$ to some convenient scale, giving $O G$; resolve $O G$ into $O H$ and $O I$, the currents in $Z Z_2$ and $Z Z_1$.

Lay off $O K = O H \times Z$ and $O L = O I \times Z$, representing the drop in the two motor phases connected to the starter. Lay off $O M = O G \times Z$, the drop in the third motor phase.

The triangle $K L M$ now gives the values and the relative phase relations of the terminal electromotive force.

The starting torque on a single-phase circuit is

$$T_1 = T_2 \frac{\text{area of triangle } K L M}{e^2 \frac{\sqrt{3}}{4}}$$

If the motor is delta-connected use equivalent star values and proceed as above.

In case we have a motor wound as shown diagrammatically in Fig. 3, Z being the main winding and Z_1 the high resistance starting winding, we first find the starting torque of a two-phase motor having two windings like the main winding.

This is -

$$T_2 = \frac{2 e^2 r_s}{Z^2 \, 746}$$

Then referring to Fig. 4, lay off $O A$ to represent the ampere-turns of the main phase, the direction being such that

$$\text{tangent } d = \frac{r}{x}.$$

Draw $O B$ = ampere-turns of starting winding,

$$\text{tangent } a = \frac{x_1}{r_1}.$$

Then the starting torque is

$$T_1 = T_2 \frac{O A \times O B \sin \phi}{(O A)^2}$$

Presented at the Conference on the Conservation of Natural Resources, White House, Washington, D.C., May 13-15, 1908.

CONSERVATION OF POWER RESOURCES

BY H. ST. CLAIR PUTNAM

Without disparaging other aspects of our progress, it is not too much to say that our time is preeminently the age of power. This applies to the world at large, but especially to the United States. Our population is increasing with unprecedented rapidity, but our mineral production is increasing so much more rapidly that some have called this the age of metal. Steel, copper, and wood are combined in mechanical devices at a rate increasing more rapidly than ore production, so that others have characterized this as the age of the machine; yet that aspect of modern life which most impresses the student of progress is the increasing use of mechanical power through the development of prime movers and the utilization of new power sources. Rapidly as our population advances, it is outrun by metal production, and that in turn by machine building; yet our most rapid progress —the feature in which our advancement exceeds all others— is in the development and use of power.

Historical division. Historically considered, the utilization of our power resources has undergone three characteristic phases of development.

In the first, power was produced directly by natural forces such as falling water and wind and its use necessarily was limited to those places where these natural forces were found. This led to the early manufacturing establishments of New England grouped about easily available water powers. This might be called the period of water powers, and in this country it held ascendency in the manufacturing industries until about 1870.

The second phase was characterized by the development of the steam engine which rendered practicable the utilization of the stored energy in fuel as a source of power. During this period the development of coal mines and rapid growth of our railway systems imparted a tremendous stimulus to commercial enterprise. Proximity of water powers was no longer controlling, and factories were established at points selected by reason of the availability of raw material, labor, transportation facilities and markets, as well as power supply. As in the first period, however, the power necessarily was used where developed, and the size of the plant was limited to the requirements of the individual user.

*Electric power.** Electrical transmission of power is the new art which now is resulting in another and radical change in methods of utilizing our power resources, permiting, as it does, development whether by water power or by steam at points most convenient and economical, and transmission to the consumer in form adapted to great variety and convenience and use. This new development in applied science calls for reappraisement of the sources from which our power is derived. The size of the power plant is no longer limited to the requirements of the individual user, but the power for entire communities can be supplied from a single station. The enlargement of this field of work newly opened by the electric transmission of power from great distances is now in active and practical development. As a result rapid changes are taking place in the methods of using power. New economies are possible of accomplishment and the resulting effect upon the conservation and utilization of our power resources is of the greatest importance.

Fuel supply. Where power is developed from the combustion of coal, wood, oil or gas, our natural resources as such are destroyed and they cannot be replaced, excepting to a limited extent in the case of wood and similar products. The supply

* Electricity, of course, is not a source of power—it is simply the agent by which energy developed from fuel and water is transmitted to the mechanism which utilizes it. In speaking of electric power, therefore, it must be borne in mind that such power is always produced primarily by water wheels, turbines, steam engines, or gas engines. With reference to their source, therefore, we have only water power and fuel power to consider, but with reference to application it is convenient and instructive to compare water power, steam power and electric power; the two former being applied directly through mechanical means to the work, while the last named has its origin in one or the other of the former and is applied through motors.

of natural oil and gas is limited and uncertain and the amount available is required for special industries. The coal production of the United States for the year 1906 was 414,157,278 tons; for 1907, about 450,000,000 tons. If the production of anthracite coal is continued at only its present annual rate the supply will be exhausted in 60 or 70 years. Since the beginning of our coal industry the total production has doubled approximately every ten years. Assuming that this rate of increase cannot be maintained, but will become constant in about 150 years, it is estimated that the supply of bituminous coal will be exhausted in approximately 700 years.* But that the coal production should become constant even 150 years hence, implies that our industries must become stationary, unless other power resources are found. We cannot look forward to such a condition with equanimity. Without coal our domestic and industrial life is inconceivable, and our existence in great cities and crowded communities is impossible unless a substitute is devised. The future welfare of the nation requires that all practicable means be employed for the conservation of the supply of coal.

Available water powers. Where power is derived from water, winds, and tides, only energy otherwise wasted is used. The energy thus extracted is added to our assets instead of being a permanent loss as is the case with the combustion of coal. It is now feasible and practicable to develop water powers, whereever located, for electric power. In the aggregate the available water powers of the nation greatly exceed the present power requirements, but unless there is some curtailment in the rate of our development, our water power resources, while being of great magnitude, will not of themselves solve the problem of our future supply of power. The amount of water power available in the United States is not known. Some partial estimates have been made, but these are necessarily approximate, as exact figures can be obtained only after careful survey and study not only of the existing physical conditions, water flow, and available reservoir capacity, but of the practicable auxiliary steam power that can be profitably installed. The power of Niagara has been estimated, by Professor W. C. Unwin, at 7,000,000 h.p. A partial estimate of the water powers of

* "How long will our coal supplies meet the increasing demand of commerce?" by Edward W. Parker, U. S. Geological Survey. Presented before the American Society of Mechanical Engineers, 1907.

the upper Mississippi river and tributaries places the available water power at about 2,000,000 h.p. The southern Appalachian regions can furnish a minimum of nearly [3,000,000 h.p.* Both of these estimates can be greatly increased by including the use of regulation reservoirs and auxiliary steam plants. The water powers of New England are more fully developed than elsewhere in the country, though much remains yet to be done. In the Rocky mountains and the far west there are immense water power possibilities; in the state of Washington alone there are 3,000,000 h.p. available;† and Governor Pardee estimates that the streams of northern California are capable of producing 5,000,000 h.p. Even approximate data upon which to base an estimate of the total amount of available water power in the country are lacking, though a good start toward collecting them has been made by the Geological Survey, with the limited means at its disposal. It is probable that the water power in the United States exceeds 30,000,000 h.p., and under certain assumptions as to storage reservoirs this amount can be increased to 150,000,000 h.p. or possibly more. Much depends upon whether regulation reservoirs and reserve steam plants are included in the estimate. Both have been demonstrated to be practicable, and undoubtedly should be considered in any estimate made of the available water power resources of the country.

Using the smaller figure of 30,000,000 h.p. as an illustration, to develop an equal amount of energy in our most modern steam-electric plants would require the burning of nearly 225,000,000 tons of coal per annum, and in the average steam engine plant, as now existing, more than 650,000,000 tons of coal, or 50%, in excess of the total coal production of the country in 1906. At an average price of $3.00 per ton it would require the consumption of coal costing $2,000,000,000 to produce an equivalent power in steam plants of the present general type.

The supply of water power is limited, however, when the rapid rate of increase in our power requirements is considered, and great care, therefore, must be exercised to insure the preservation of our water power resources and to secure the maximum practicable development.

* "Water Powers of the Upper Mississippi and Tributaries," and "Water Powers of the Southern Appalachian System," by M. O. Leighton, Chief Hydrographer, U. S. Geological Survey.

† Computed by F. G. Moorhead, in *The World's Work*, April 1908, p. 10091.

Total power used in United States. Using the data furnished by the census returns of 1900, 1902, and 1905 as a basis and applying the prevailing rate of increase in the industries included in these reports, and adding an equivalent amount for the steam railroads, it is estimated that the total installed capacity of prime movers in all our land industries for the year 1908 approximates 30,000,000 h.p.[A] (Fig. 1.)

The average load on steam and other engines is much less than their rated capacity, and, owing to the overlapping of loads, it is probable that the total average load does not exceed one-third or one-quarter of this amount.

Rate of increase. During the last thirty years the total amount of power used in our manufactories and other industries, as recorded by the census, has doubled approximately every ten years. The fact that substantially the same rate of in-

[A] The following table compiled from the latest census returns gives the installed capacity of prime movers in the United States in the industries named at the dates mentioned:

	Installed horse power.
Manufactures, census 1905	12,765,594
Mines and Quarries, census 1902	2,753,555
Street Railways, census 1902	1,359,289
Electric Light and Power Stations, census 1902	1,845,048
Telephones, Telegraph and Fire Alarm Systems, census 1902	3,148
Custom Flour, Grist and Saw Mills, census 1900 (omitted from census 1905)	883,685
Steam Railroads, data from Statistics of Railways, 1905, equivalent power	3,750,000

These figures include prime movers only. Duplications in the way of electric, water and air motors and rented power have been omitted. The equivalent power used by the steam railroads is based upon the result of calculations made by Lewis B. Stillwell and H. St. Clair Putnam in a paper presented by them to the American Institute of Electrical Engineers, January, 1907, "On the Substitution of the Electric Motor for the Steam Locomotive," and represents the installed power house capacity required for their electric operation in the year 1905. Based upon maximum draw-bar pull, the power of the 46,743 steam locomotives in the United States (1904) averages 600 horse power (census 1905) but the power developed when averaged over the entire year approximates only 40 horse power. In order, therefore, that the estimate of total power in the United States should not be misleading, the power used by our steam railways has been taken at a figure that is comparable with the installed power in other industries as, for example, in electric railways where the installed capacity in the power houses has been taken rather than the rated power of the motor equipment, which is many times greater than the power house capacity required for their operation.

crease has existed in coal production, railroad gross earnings, freight ton-mileage, passenger mileage; and the value of agricultural products, as well as in total power consumption, is a striking demonstration of the close interrelation and mutual dependence of these great factors which, in the aggregate, measure the industrial progress of the nation.

We cannot foretell how long the present rate of increase in our industrial enterprises will continue. This will be determined by the general laws which govern industrial development

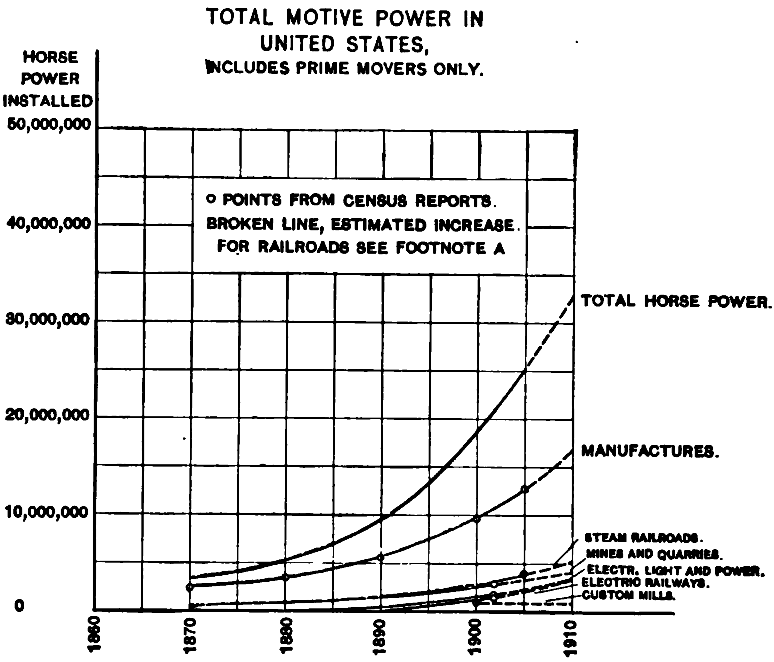


Fig. 1

and by the increase in wealth. It is clear, however, that if our power resources are exhausted or wasted the result will be disastrous.

Relative use of steam, water power, etc. Of the total estimated power at present produced by prime movers, about 26,000,000 h.p. is produced by steam engines, (Fig. 2) 3,000,000 h.p. by water motors, (Fig. 3) and 800,000 h.p. by gas and oil engines, (Fig. 4). These figures emphasize the present position of the steam engine in our industrial development and the relatively much less important place now occupied by water power, (Fig. 5).

Growth of electrically applied power. Of the total 30,000,000 h.p., including the railroads, used in the country, it is estimated that 9,000,000 h.p., (Fig. 6) or 30 per cent., is now utilized electrically (Fig. 7).* This highly remarkable growth has been accomplished in 25 years. The use of electric power at the present time is being doubled approximately every five years, as contrasted with the phenomenal doubling of the total power

TOTAL STEAM POWER IN UNITED STATES.

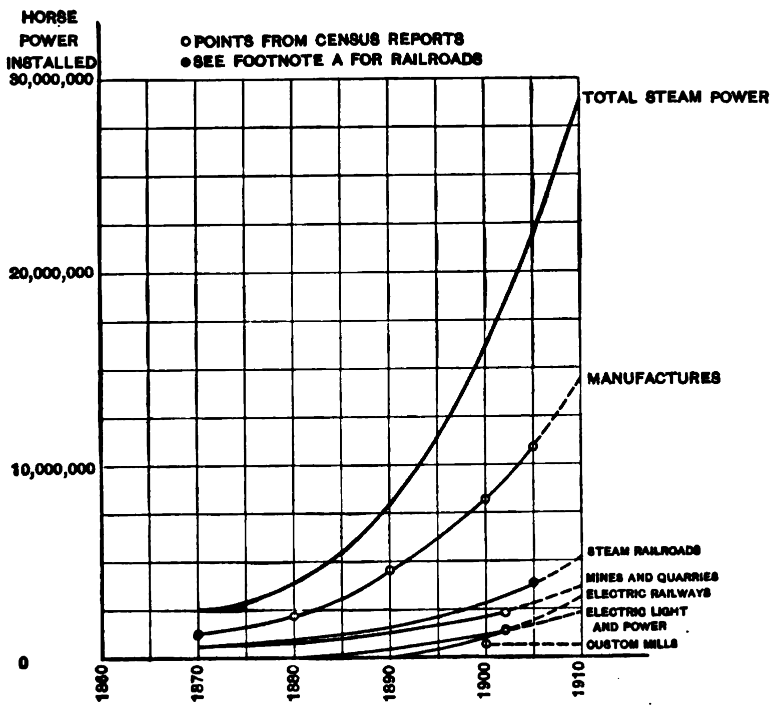


Fig. 2

every 10 years. If the present rate of increase is maintained, electrically applied power will equal or exceed the power mechanically applied in 1920. This great growth is due to the convenience, earning capacity, and economy resulting from

* This does not include the electric power generated in isolated plants and used for other purposes than manufacturing. These plants are not included in the census reports, and while they are individually small the aggregate electric power developed is large.

the use of electrically applied power. The significance of this remarkable increase in the use of electric power in manufactures and other industries lies in the market thus provided for the utilization of our water powers wherever located and whatever their magnitude.

Economies due to electric power—steam power. Where coal is the source of power, electric transmission and distribution

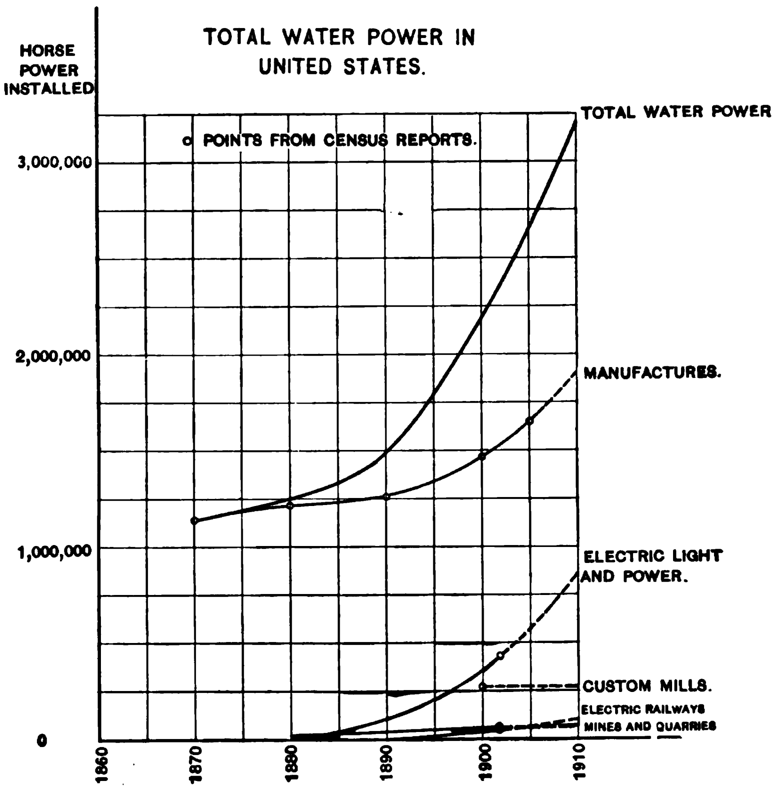


Fig. 3

greatly reduce the amount burned to perform given mechanical work. This results from the substitution of a few large and highly efficient boilers and engines for a larger number of relatively small and uneconomical ones and from the introduction of plant economies and skill in operation not attainable in the smaller plants. A material saving is effected also in the application of the power directly to the work through motors instead of indirectly through inefficient countershafting and belting.

A further material gain also results from the fact that a large plant carrying the load formerly carried, for example, by one hundred small plants is operated under conditions more nearly approximating uniformity of load and therefore at higher economy.

Greater economy can be obtained, even in our large plants, through the more general use of so-called fuel economizers, superheated steam, higher vacuum, and better combustion under the boilers. We may expect still higher efficiency from the

TOTAL INSTALLED CAPACITY OIL AND GAS ENGINES IN UNITED STATES

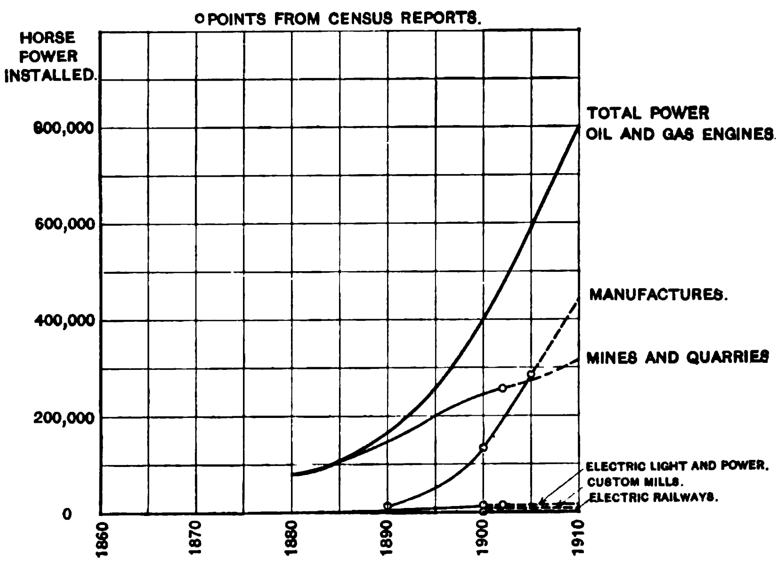


FIG. 4

development of larger boiler and engine units. These economizing appliances, which are relatively unimportant in small plants, become of great importance in large plants, and will have still greater influence on steam practice as the price of fuel increases and the cost of capital decreases.

Fuel economy of gas engines. This discussion would be incomplete without mention of the great possible fuel economy that may result from the use of gas and other similar engines. Though engines of this character antedate the use of the electric motor, their development has been slow, and they occupy a relatively unimportant place as power producers. The ordinary steam engine utilizes not more than four or five per cent. of the heat energy in coal, and our best modern steam electric plants show a heat efficiency not exceeding 10 or 12 per cent.* With the gas engine and producer gas the heat efficiency can be more than doubled, and still higher efficiency seems probable with higher compression or through the use of other possible improvements.† This is a most promising field for development

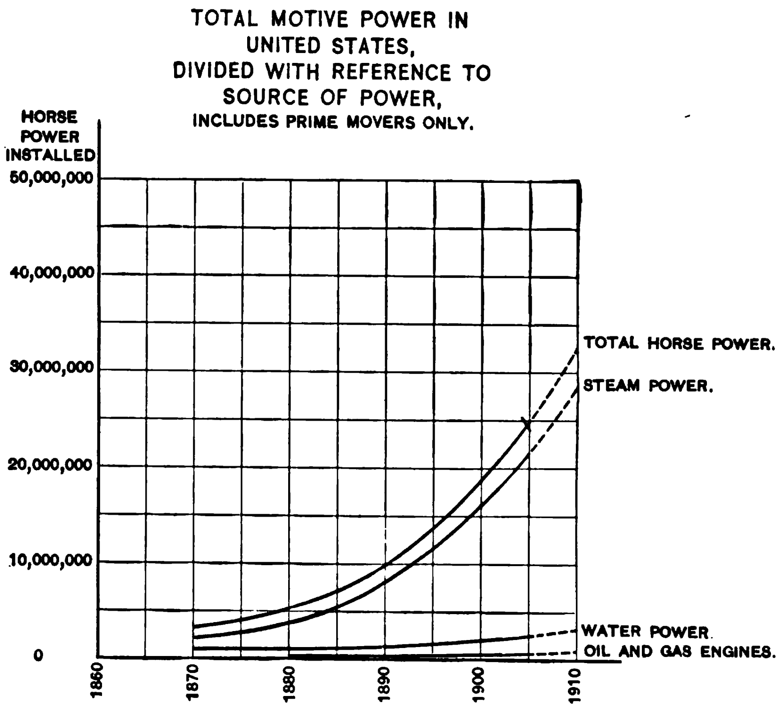


FIG. 5

and it is entirely possible that the gas engine may revolutionize our methods of using fuel for the production of power.

Beyond these gains, which may be considered well within the limits of possible attainment by present knowledge, there stands the theoretical prospect of still greater economies, the

* "Power Plant Economics," by Henry G. Stott, presented before the American Institute of Electrical Engineers, January, 1906.

† Report of F. W. Burstall to the Gas Engine Research Committee of the (British) Institution of Mechanical Engineers.

possibility of which cannot be denied so long as methods employed in developing energy from coal results in a waste of from 75 to 95 per cent. of the potential energy which nature has stored in the coal. But the science of the present time does not permit us to assume any radical increase in efficiency of fuel engines beyond the limits which I have indicated, and our only safe course is to base our estimate upon the progress of the present

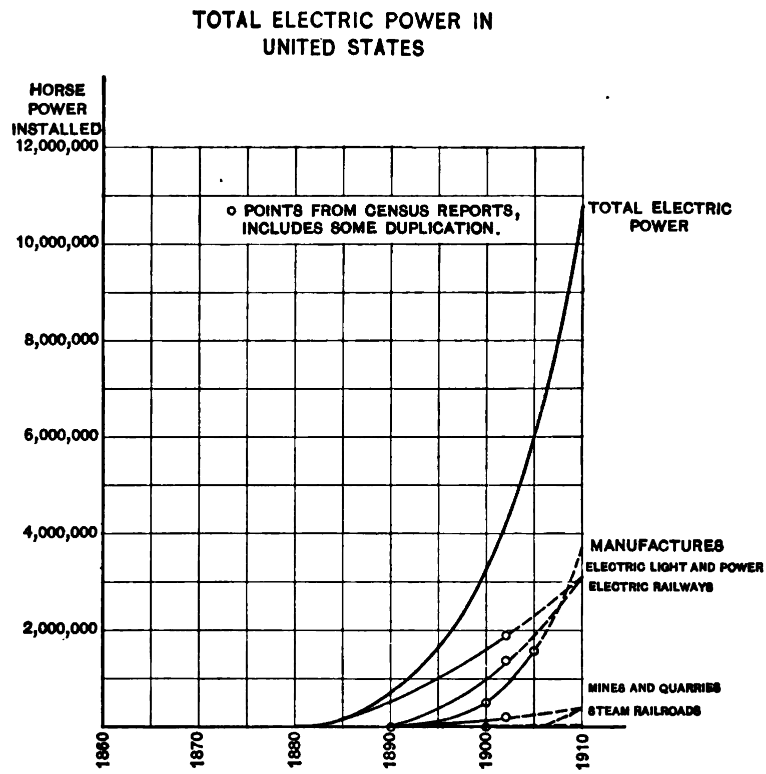


FIG. 6

time with such reasonable allowance for improved economy as is dictated by recognition of progress of the art along lines now within the horizon of possible science.

Water power economies. Where water power is the source of supply, electricity promotes economy for reasons identical with the foregoing, except that absence of fluctuation of load is relatively less important, but the great gain which results from electric transmission is the utilization of water powers remote source of power is thus far paramount in them all, but the percentage of electrically applied power is increasing at nearly double the rate of increase of the total power used.

Electric lighting. The extraordinary growth of the electric lighting industry is familiar to all. Unfortunately the results of the special census of 1907 are not yet available, but the indications are that the five years which have elapsed since the previous census will show phenomenal growth. During these five years the gross sales of the great electric manufacturing companies have doubled, and the proportion of the output consisting of electric power apparatus and generating units of large size has greatly increased. An influential factor in the growth during this period has been the rapid development of long-distance hydroelectric power transmission plants.

Electric railways. Since the displacement of horse and cable cars in the cities a few years ago, electric railways have been extended to suburban and interurban districts and are rapidly forming a network over the entire thickly settled portions of the country. In the nature of their traffic, many of these roads are scarcely distinguishable from steam railroads, and many railroads are using them as feeders. In a few cases railroads have converted steam operated branches into electric lines.

Electrification of steam railroads. A beginning is being made in the electrification of our steam railroads. The New York Central, the Pennsylvania, the Long Island, the New York, New Haven & Hartford, the Grand Trunk, the Great Northern, the Erie, the Southern Pacific and others have electrified portions of their lines, and most of these are now in successful operation. Many of these roads are extending their electric zones. Thus far most of this work has been induced by terminal requirements, tunnels, heavy grades or other special conditions which emphasize the advantages to be derived from electric operation. The increase in capacity, convenience, and greater earning power as well as the economies resulting from electric operation will stimulate the electrification of steam railroads, just as these factors have stimulated the use of electric power in other industries. The problem presented is larger because of the necessity of interchangeability of equipment, and the development must necessarily be gradual on account of the magnitude of the interests and the large capital expenditures involved. The railroads are among the largest consumers of fuel, and electric operation, exclusive of the use of water powers, would reduce the coal consumption to less than one-half of that required for similar operation with steam locomotives.*

Tendency toward greater use of water powers. During the past few years, there has been renewed interest in water powers on account of the practicability of their use for the generation of power and the electrical transmission of this power to distant markets. The great hydroelectric development at Niagara was the first large enterprise of this character and has demonstrated its practicability. The census of 1905 gives a partial list of long-distance hydroelectric plants developing power aggregating 600,000 h.p. and this list can now be largely increased. Our most desirable water powers are being absorbed rapidly, and it becomes important, therefore, for us to take stock of our water resources and formulate plans for their control and proper utilization.

Inland waterways. In the improvements that have been made on navigable rivers, too little attention has been given to the development of the incidental water powers. On some waterways, as in several instances on the Mississippi, immense sums of money have been appropriated and expended on especially difficult portions of the river. If this money could have been made available in large amounts, instead of by driblets over periods of many years, water powers of great value could have been developed and the navigation effectively and permanently improved. Unfortunately this has not been our policy. Too often the appropriations have been inadequate for carrying out the work as it should be done, and frequently the work has not followed any well-digested plan.

With the data at hand, it is impossible to make an accurate estimate of the amount of power that can be developed incidentally to river navigation. A partial estimate of the power developed at existing government locks and dams places the amount at 1,600,000 h.p.† This is based on the mean low-water discharge for three months. This subject should receive careful consideration. Improvements in navigation should be made only after thorough study of the possibilities of power development. On the other hand, many water powers are on

* "On the Substitution of the Electric Motor for the Steam Locomotive," by Lewis B. Stillwell and H. St. Clair Putnam, presented before the American Institute of Electrical Engineers, January, 1907.

† "Available Water Powers of United States Government Locks and Dams," collected by M. O. Leighton, United States Geological Survey.

streams that are navigable, or are capable of canalization, and these streams should be developed for power purposes only after careful examination has been made of the possibilities of the stream forming a link in the system of inland waterways.

Canalized rivers. There are many streams that are not now navigable, or are navigable for only a portion of the seasons, that can be canalized and converted into streams of great commercial value. The use of our waterways for both power development and navigation causes no conflict; these uses are in fact correlated and their interests harmonious. Where it is necessary to place a dam across a stream to develop power, the slack water so produced, with the addition of locks, renders otherwise impassable stretches of river available for navigation. Every water power development is vitally interested in obtaining a uniform flow of water. This exactly meets the requirements of navigation. The approximate realization of regularity of flow can be attained only by the construction of headwater regulating reservoirs and the preservation of our forests. Every water course that is improved for the production of power and for navigation produces, therefore, vigorous self-interested allies in the cause of forest preservation, headwater regulation, and the maintenance of conditions which are favorable to both interests.

Canals. Considerations which affect the use of our rivers and streams, as sources of power and for navigation, apply also to canals. Heretofore, canals built for transportation purposes have not been used, to any great extent, for the development of power. In some cases this has been on account of the limited supply of water, but more frequently it has been due to the great difficulty experienced by the animals in towing boats against the rapid current produced in the canal by the flow of water to the water wheels. In recent tests it has been demonstrated that canal boats can be towed by electric towing machines at a much lower operating cost than is possible with animals, and that operated in this manner the speed can be greatly increased.* The first cost of electric equipment is relatively large, but the change to electric towing will pay handsomely when the volume of traffic is sufficiently large. The traffic required is well within the ultimate capacity of the canal. With

* "Notes on Electric Haulage of Canal Boats," by Lewis B. Stillwell and H. St. Clair Putnam, presented before the American Institute of Electrical Engineers, March 1908.

electric towing, the increase in the rate of current flow introduced by the development of water power on the canal is not a serious impediment to navigation.

Irrigation. There are large areas in the Western states where the soil is of wonderful fertility, but irrigation is essential to the successful growing of crops. The cultivated lands usually lie in valleys and water is carried to them through long and ofttimes wasteful irrigation ditches. In many cases the water could be utilized for developing power on the headwaters of the streams without injury to the irrigation interests, as is illustrated by the excellent work now being done by the Reclamation Service. The development of water power will introduce another party whose self-interest dictates the use of every available method of preserving the volume of water supply, its continuity, and regularity of flow.

In some cases irrigation channels can be converted into canals suitable for at least limited navigation, and where practicable this should be done. Some types of apparatus as now developed for towing canal boats by electricity require but little space along the side of the ditch and can be installed, usually, without additional grading wherever an irrigation ditch can be constructed. Electric towing cannot be economically practicable, however, unless the traffic reaches a considerable volume. With animal power the additional capital investment is small and is proportional to the amount of business handled. With electric towing the first cost is large and manifestly sufficient traffic must be secured to meet the capital charges before profits can be realized.

Water supply. What has been said upon the subject of irrigation canals applies to the development of the water supply for our cities. This work, like irrigation, should be carried out so as to develop the maximum water power possible without injury to the water supply.

The preservation of the purity of water for domestic use is of great importance to the welfare of the nation. A consideration of this subject, as well as of navigable water-ways, canals, irrigation and water powers, emphasizes the absolute necessity of competent supervision of the natural water resources of the country.

Regulation of stream flow. The flow of water in many streams annually fluctuates between wide limits. The low-water periods limit the profitable water power development and the high periods often cause disastrous floods. On most streams the average rate of flow for the year is many times the minimum flow. It is possible in some cases to utilize a flow approximating the average by constructing controlling reservoirs on the headwaters of the stream. Our Great Lakes form a natural reservoir of this character for the Niagara River. The Upper Mississippi has great natural reservoirs which assist in regulating its flow and which easily can be made very effective in its control. The notable floods of the Ohio River can be greatly reduced by the construction of controlling reservoirs on its headwaters which will result in the saving of millions of dollars now annually destroyed. On a stream which I recently investigated the minimum flow furnishes but 200 h.p. The construction of a storage reservoir increases the continuous 24 hr. power that can be utilized to 8000 horse power. If storage reservoirs could be constructed on the Susquehanna River, upon which a great water power development is now in course of construction, so as to obtain a uniform flow throughout the year, the available power at this site would be increased from a minimum of 30,000 h.p. to 200,000 h.p. While it is impracticable to construct reservoirs capable of holding back all flood waters, it is nevertheless certain that material gain would result from well-directed efforts along the lines suggested.

Auxiliary steam plants. On account of the great annual fluctuations now existing in stream flow, it has been found profitable to install steam plants supplementing the water power during seasons of low water. This method on account of its expense greatly handicaps the full development of our water powers and increases the amount that must be charged for the power. Under given conditions the most profitable amount of water power to develop and the best size of steam plant to install can be determined with great accuracy. The reserve steam station need not be located at the water power; in fact, it preferably should be located at or near the market for the power when that is distant, as greater reliability and continuity of power supply is thus secured. Headwater regulation would greatly reduce the necessity for such auxiliary steam plants.

Similarly the water power which can be purchased economically by a prospective customer who already has a steam plant in operation can be accurately determined. This amount depends upon the relative cost of generating different portions of the load by steam as compared with the amount charged for the water power supplied. In its economical application this method of operation works out so that the water power plant carries the steady portion of the load where the coal consumption per horse power capacity is greatest, and the steam plant is called upon to carry the peaks only where the coal consumption per horse power is least.

Interconnected plants. In addition to their reserve function in time of low water or flood, auxiliary steam plants and interconnected plants are valuable as insuring the continuity of power supply. If the lines are run overhead, as they must be for long-distance transmission in the present development of the art, all electric transmission plants are subject to occasional short interruptions due to storm, lightning, or malicious mischief. It is economical and desirable to tie together two or more plants, thus greatly increasing the reliability of service. If one plant or transmission line fails the others can be pushed to take the load. From an engineering standpoint, and from the standpoint of the customer as well as the power producer, this method of operation has great advantages.

Importance of power resources. In 1905 the value of the product of our manufactures amounted to $16,866,706,985; the total receipts of the steam railroads were $2,325,765,167.

In manufacturing, the value of the product was $1,152 for each horse power installed, and the yearly wages amounted to $248 per horse power.

In the railroad industry the gross receipts amounted to $555 and the yearly wages to $224 per horse power, rated on a basis comparable to that used in the census report covering manufactures.

I have selected these two classes of industry for the reason that they use the bulk of the power and illustrate its tremendous productiveness in increasing our wealth.

On the basis of the lower estimate of water power already mentioned, namely, 30,000,000 h.p., and applying the ratio which now exists between wages paid and power utilized in manufacturing and railroad industries, the development of this amount of water power implies an increase in wages paid amounting to about $15,000,000,000 per annum, an amount more than double the total value of our agricultural products at the present time.

Collection of data necessary. These figures emphasize the vast financial importance of our power resources and the necessity of their conservation and their intelligent development. Much can be accomplished by the national government in connection with irrigation of national lands and the improvement and preservation of navigable waters. The state governments can greatly assist in this work, within their respective territories.

Census of water resources. A reliable census of water resources is greatly needed. The Geological Survey has accomplished much in measuring and recording the flow of streams, but the work done is small as compared with that which remains to be done. Obviously, in order that records of this character shall constitute a uniform and safe basis for the very large capital investment which must be made in the future in order that our water power resources shall be properly utilized and our fuel supplies conserved, they should be made under the immediate direction of the national government.

Research work. The national government can render great assistance also in the research work which it has undertaken into the better utilization of our fuels. Excellent results have been obtained by the able body of engineers engaged on this work, but when we consider that we are now utilizing but five or ten per cent. of the heat value in fuels it is evident that much remains to be done.

Necessity of government regulation. Power and transportation are the two great physical bases upon which modern industrial development rests. Without power our methods of transportation must revert to a level with those existing in China. Up to the present time while nation and states have regulated and in some degree aided in the development in transportation, the power resources of the country have been utilized or wasted by the private individual and the corporation with little hindrance and still less regulation by the constituted authorities. Next to individual enterprise the most essential factor in the development of our national resources is wise governmental guidance, so applied as to insure the vigorous working of individual initiative and at the same time prevent the waste by individuals of that which is vital to our national welfare and to secure in the utilization of our natural resources the highest practicable degree of economy which scientific knowledge and engineering skill can attain.

A paper presented at the annual meeting of the American Institute of Electrical Engineers, New York, May 19, 1908.

COMPARATIVE TESTS OF LIGHTNING PROTECTION DEVICES ON THE TAYLOR'S FALLS TRANSMISSION SYSTEM

BY J. F. VAUGHAN

Recent Institute discussions have brought out a decided difference of opinion on the value of certain lightning protective devices and have expressed a demand for positive data on line protection especially. This paper furnishes data obtained last summer on an operating line experimentally equipped with various protective devices. The results are of especial interest in being actual records made by means of tell-tale papers applied not only to the station protective devices but also to those on the line, and even to the line insulators themselves throughout the system.

When the transmission from Taylor's Falls to Minneapolis Minnesota, was built in 1905, local conditions demanded the best lightning protection available. The line ran southwest from the power house a distance of about 40 miles through a rolling country, partly wooded and full of lakes and swamps. It lay in the natural path of thunderstorms forming to the northwest of Minneapolis. Investigation indicated a zone about 9 miles long near the middle of the line that was especially subject to severe lightning, and the splintering of six poles in different parts of this zone before any wire was strung suggested the necessity for special protection at exposed points against direct stroke.

On account of the wide divergence of opinion on the subject of lightning protection, and the impossibility of reconciling the conflicting results of practice, it was decided to try out on the Taylor's Falls System all existing devices of promise and such others as might be devised, in order, by comparing them in actual service, to work out some effective scheme for future protection.

Description of system. Current is generated by four 2500-kw., 2300-volt, 60-cycle, three-phase water-wheel driven ma-

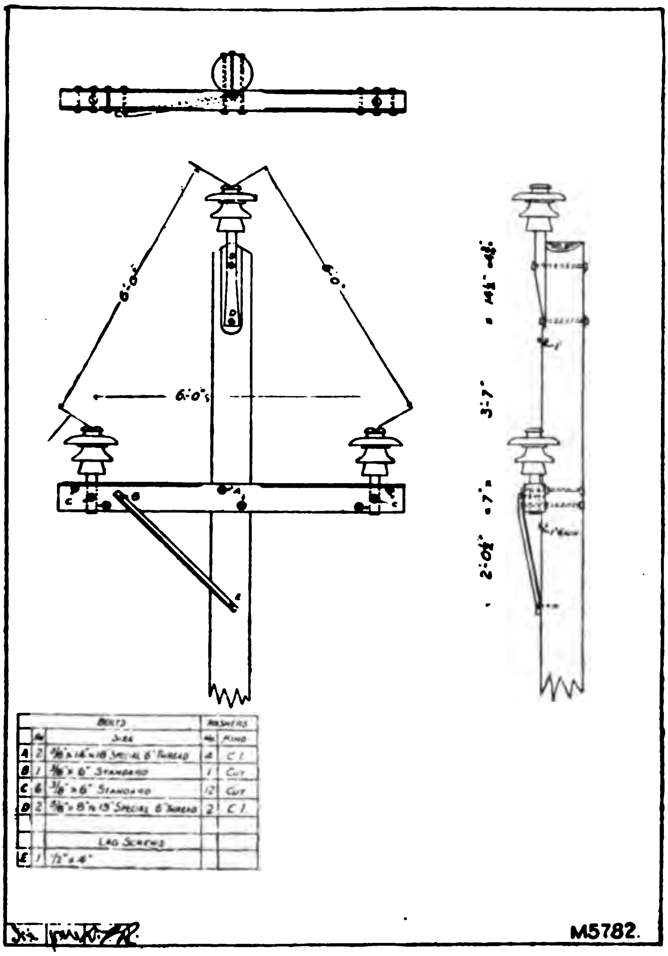


FIG. 1

chines, each operated as a unit, with a bank of three 900 kw. transformers connected delta-delta and stepping up to 50,000 volts. The pressure is stepped down at the main sub-station on the outskirts of Minneapolis to 13,800 volts for local distribution and transmission to a steam and water power local plant in the city. Automatic time-limit relay oil switches control the lines and transformers at all three plants.

The transmission consists of a single line built on private right-of-way using Idaho cedar poles of 45 ft. standard length,

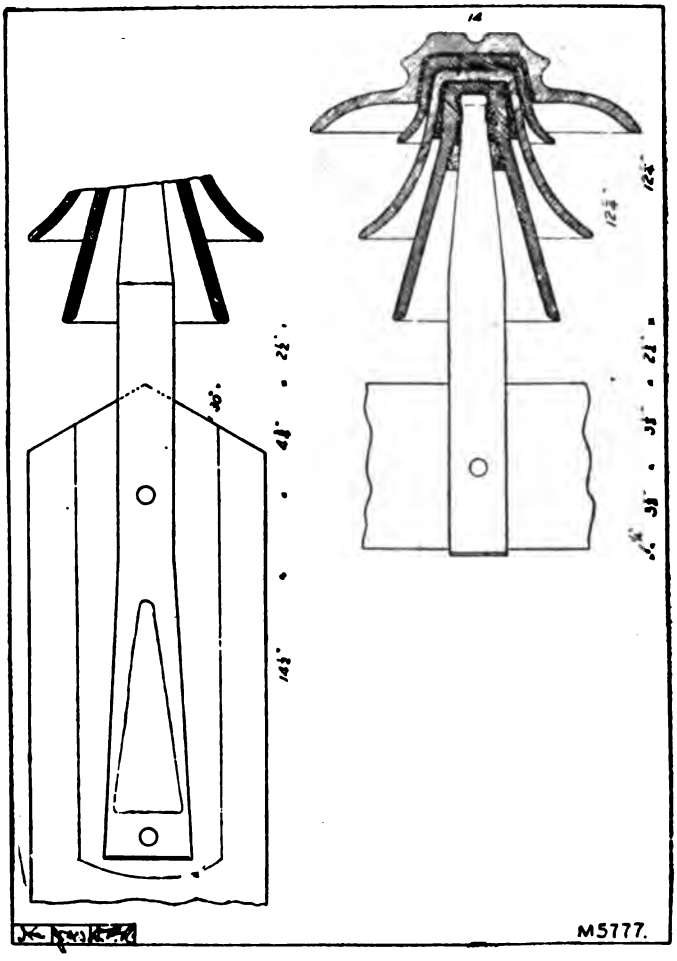


FIG. 2

carrying three 0000 semi-hard-drawn copper cables supported on 14 in. four-part porcelain insulators arranged on a 6-ft. equilateral triangle with the apex at the pole-top (Fig. 1). The insulators (Figs. 2 and 3) were originally selected from a number of samples, including five others of the writer's design,

FIG. 3—Photograph of insulator flash-over, under artificial rain test

as the only insulator obtainable which, under driving rain test, showed properly distributed electrostatic stress without concentration on any one part. These had already proved unusually rugged, as shown by two years' use, without any electrical failures on 75 miles of 57,000-volt transmission on the Puyallup system in the state of Washington. The insulators are supported on iron-pipe pins cemented into them and bolted to the pole-tops or set into the cross-arms. The line also carries a pair of telephone wires on an arm 7.5 ft. below the transmission arm.

The telephone system consists of a metallic circuit of No. 10 copper wire mounted on porcelain insulators of the same design as the ordinary double petticoat glass type. Instruments are permanently connected at the power house, sub-station, and inspector's cottage at the middle of the line, and booths provided at various points for tapping in inspectors' portable instruments.

Station protection. For protection of the power house and sub-station low-equivalent multigap arresters and oil-insulated choke-coils were installed, supplemented at the sub-station by a set of experimental aluminum cell-type arresters connected to the entering line through a small number of arrester gaps in zigzag arrangement, set so as to be normally active.

The transformers at all stations were further protected on their low-tension sides by static discharge gaps.

Line Protection.

Horn-type arrester. Three types were installed, one at each end and one in the middle of the line, primarily to pass off disturbances of unusual magnitude, and also to experiment with the different forms.

The sub-station arrester consisted of a single gap on each phase, arranged with a sheaf of water jets forming series resistance to ground. This required too much water and was replaced by tanks of water with terminals of carbon rods in fiber tubes (Fig. 4).

The power house arrester had two gaps in series between each phase and ground, with the second gap shunted by carbon terminals placed in the river (Fig. 5).

The Hugo arrester, at the middle of the line, was built on the selective resistance principle, with three gaps in series on each leg, the second and third gaps being shunted by water-box resistances (Fig. 6).

Overheaded grounded wires. Four types were erected in the nine-mile zone in 0.5 mile lengths, alternating with 0.5 mile lengths of unprotected line as follows:

Type *A*. Two wires mounted on a cross-arm 5 ft. apart on either side of the top line wire and about 18 in. below it (Fig. 12).

Type *B*. Two wires supported on standards of 1.25 in. iron pipe 6 ft. apart and 18 in. above the top line wire (Fig. 7).

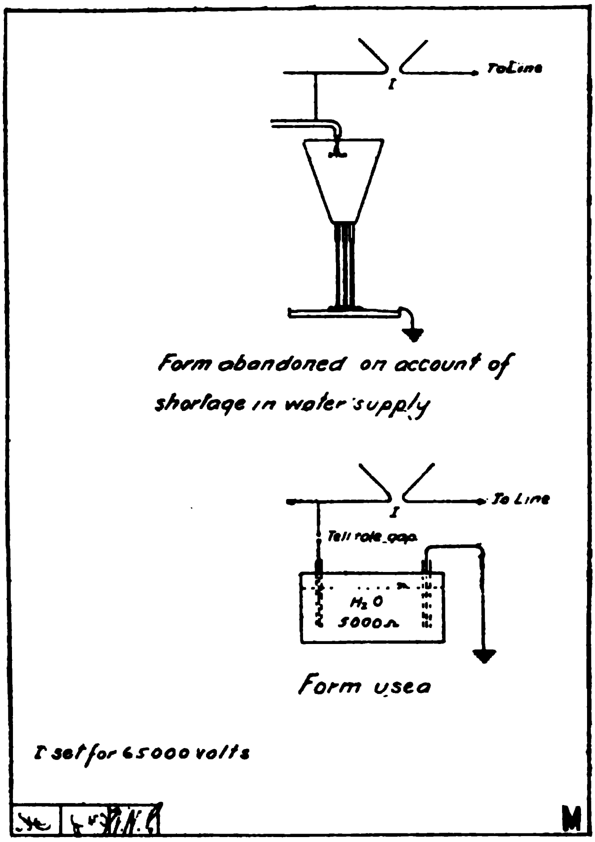


FIG. 4

Type *C*. One wire on knobs attached to the pole near the center of the delta (Fig. 12).

Type *D*. Two wires in the same position as in Type *B*, but supported on pipe pins set in the ends of a cross-arm attached near the top of the pole.

In the above constructions the grounded wires were of No. 6

hard-drawn copper. The ground connections were of 0.5 in. by 0.0625 in. galvanized iron ribbon wire at every fourth pole and the ground made by 0.75 in. galvanized iron pipe driven to moist ground.

Lightning-rods. Four types were used, erected in the nine-mile zone in sections from one to two miles long, separated by

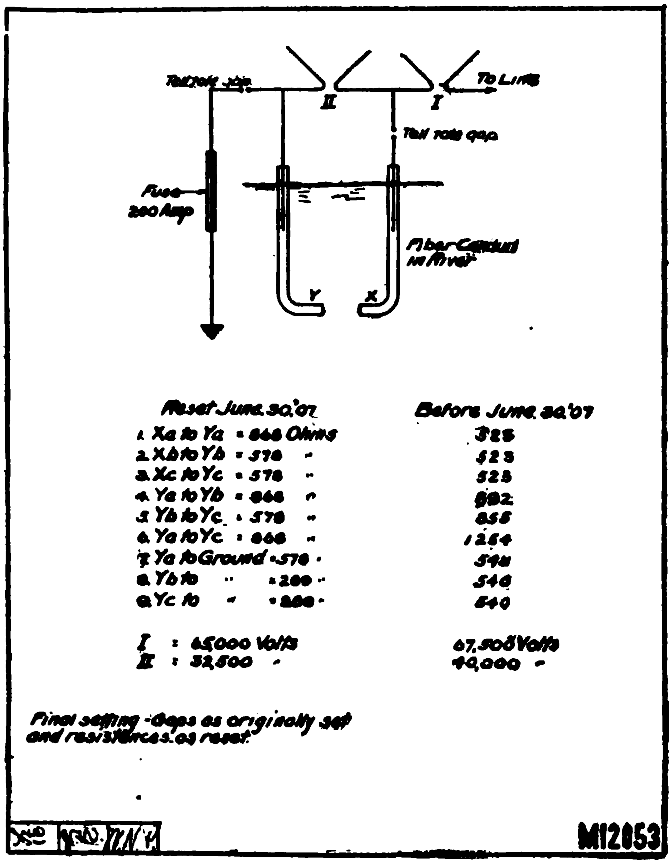


FIG. 5

unprotected sections as in the case of the grounded wire constructions as follows:

Type *A*. Rods of 1.25 in. galvanized iron pipe attached to the poles and extended by tridents of copper wire reaching 6 ft. above the top line wire (Fig. 7).

Type *B*. Rods of 1.5 in. galvanized iron pipe mounted on separate poles 20 ft. to one side of the transmission line and topped by tridents of copper wire extending 25 ft. above the top line wire. Rod poles were spaced at the centers of alternate spans (Fig. 7).

Type *C*. Same as Type *B*, but spaced three rods to four spans.

Type *D*. Same as Type *B*, but spaced 1000 ft. apart.

Ground connections were made as on grounded wire construc-

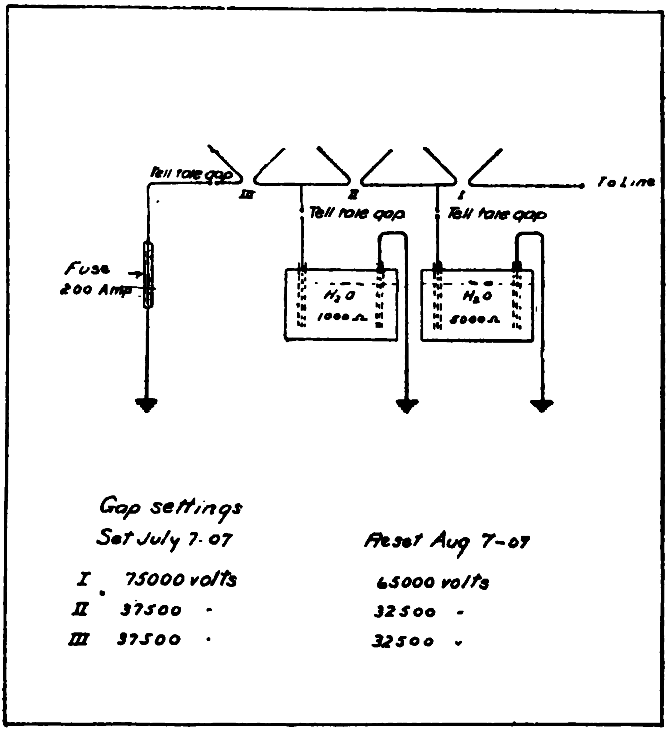
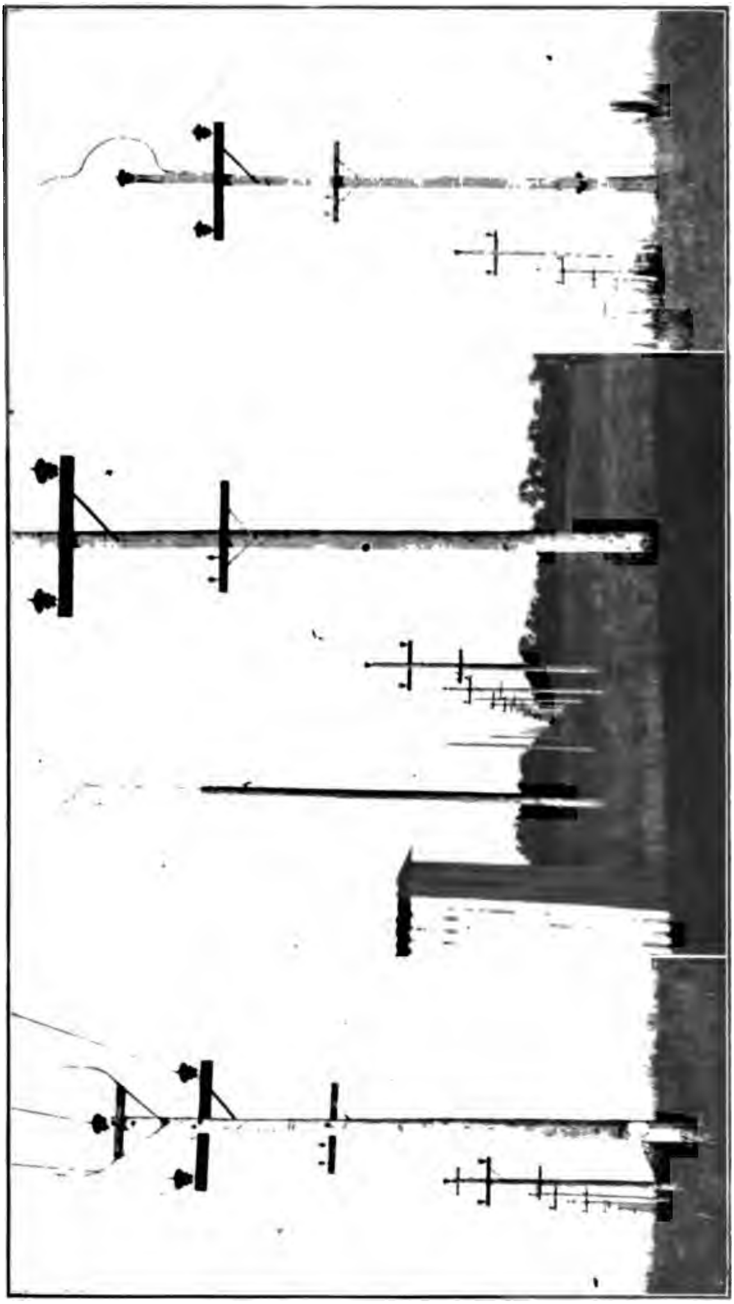


FIG. 6

tion, but with two grounds for each rod pole, one at the base of the pole and the other 20 ft. or more away, to insure especially wet ground and to increase the discharge area.

Telephone protection. Each permanent and temporary telephone connection was made through a one-to-one repeating coil and discharge gaps to ground set to break down at about 900 volts.*

* (American Tel. & Tel. Co. Protection 74-A.)



Overhead grounded wire—type "B"

Lightning-rod—type "B"

Lightning-rod—type "A"

FIG. 7

Recording devices. All station arresters were provided with tell-tale papers. To determine the character of disturbances their extent, magnitude, and effect on line and apparatus, ground connections of all protective devices were provided with gaps for the insertion of tell-tale papers.

To study the stresses on the line insulation throughout its length and the behavior of the insulators, each insulator pin at every third pole was grounded through a separate ground wire and tell-tale box (Fig. 7), supplemented by choke-coils shunted with tell-tale gaps cut into the line wires at various points.

After a number of insulators on grounded pins had been damaged, the pin grounds were removed from four sections of about one mile long each, separated by one-mile sections left grounded, to prove whether the grounding was in any way responsible for insulator failures.

Records. The following records were kept:

A. Weather conditions shown by United States Weather Bureau reports, and reports of observers along the line.

B. Storm occurrences and data furnished by local men in charge.

C. Operating and special reports of interruptions to service and damage to system.

D. Tell-tale papers collected after each storm.

E. Graphic analysis of tell-tale papers for each storm.

Operation and results of first season. The transmission system was started up in December, 1906, and lightning protection records carried through the following summer. The lightning season opened late in March and lasted into October. Thirty-two storms occurred during this season within reach of the line.

The following tabulation gives data on the storms and damage to system, or interruptions to service.

The tabulation (Table B shows that in 17 out of the 32 storms the service was interrupted and 8 of these storms caused damage to insulators, while only one storm affected the station apparatus; this was due probably to a defect in a transformer bushing, but was not sufficient to interrupt the service. Out of 42 insulators damaged, only 3 were punctured, the rest being shattered.

The plan and profile of the line (Fig. 8) show the distribution of damaged insulators on the line and indicate their phases, location on pole or tower, etc.

The following tabulation (Table A) further analyzes insulator damage.

TABLE A.

ANALYSIS OF INSULATOR FAILURES

Total number of storms	32	
Number damaging insulators	8	
Total number of insulators on line, approximately	5,500	
Number damaged	42	0.8% of total damaged
" shattered	39	92.9% " " "
" punctured	3	7.1% " " "
" top insulators	23	54.7% " " "
" on west side	6	14.3% " " "
" " east "	13	31.0% " " "
" " brace "	12	28.6% " " "
" " opposite side	5	11.9% " " "
Total number insulators on grounded pins, approx	1,650	30.0% " "
Total number insulators on ungrounded pins, approx	3,850	70.0% " "
Number damaged on grounded pins and towers	35	83.3% " " damaged
Number damaged on towers	3	7.2% " " "
" " on ungrounded pins	7	16.7% " " "
" " in sections where grounds had been removed	4	9.5% " " "
" " on more or less exposed heights	28	66.7% " " "
" " in wet bottoms	8	19.0% " " "
" " scattering	6	14.3% " " "
Number damaged under overhead grounded wires. (At or near ends only)	2	4.8% " " "
Number damaged under lightning rods on poles	3	7.2% " " "
" " under lightning rods on separate poles	0	0.0% " " "
Poles split.		
Number with pin grounds	0	
Number without pin grounds	1	
Poles burned.		
Number with pin grounds	2	
Number without pin grounds	0	

The chief operating troubles were interruptions due to short-circuits and grounds from spilling over of insulators, generally accompanied by permanent damage to a part of such insulators (Figs. 9 and 10). Another serious cause of interruption during the latter part of the season was due to too low a setting of the horn arrester at the power house; this did not appear with the higher setting earlier in the season.

TABLE B.

DATA ON STORMS AND DAMAGE TO SYSTEM

Characteristics of Storms												Damage.		
Date	Time	Location	Direction	Lightning	In. of rain	Wind Max. m.p.h.	Pole No.	Ph.	Loc.	Pin	Brace	Insulation damage	Duration of interruptions	Remarks
3/23	11:20–11:50 a.m	Dist.		Little	0.03	24								
5/12–13	9 p.m.–6 a.m.	"		Heavy	0.10	32	1532	C	Top	Gr.	—	*	None	Sub-A transformer bushing punctured. Telephone not disturbed.
6/9	3–6 a.m.	Near sub-A		"	0.10	40							"	
6/9	5 p.m.			1-flash	1.20	—							"	
6/15	8–10 a.m.			Frequent	0.30	44							"	
6/16	5 p.m.	Dist. to NW			T	32							"	
6/21	5:30–8:30 p.m.		W. to E.	Heavy	0.55	27								
6/22–3	9:30 p.m.–1 a.m.			"	0.16	30	1571	A	W-side	Gr.	Br.	*	18 hrs.	Pole 1571 burned by wire, dropping from broken insulator. Line interrupted by switching following trouble.
6/23	12–1 p.m.			Mild	0.0								None	
6/24	5-p.m.	Dist. to E.			0.0	16							"	
6/29	6 a.m.			Heavy	0.0	17	1474	B	W-side	Gr.	None	*		Insulators replaced Sunday July 1, when line shut down for repairs.
							1478	"	E-"	"	Br.	*		
6/30	12–8 a.m.	5 mi. from p.h. bet. poles 172–288.		"	0.03	23	193	A	Top	"	None	*	Line held for 1 hour after damage; then out 30 hours for repairs.	
							Tr 224	"	"	"	—	*		
							267	"	"	"	—	*		
							Tr 288	"	"	"	—	*		
							193	B	W-side	"	—	*		
							172	C	E-side	"	Br.	*		
							208	"	" - "	"	"	*		
							Tr 224	"	" - "	"	"	*		
7/4	10:30–12:30 p.m.	2 mi. east of Hugo.	W. to E.	Heavy	0.16	38	918	"	E-"	"	"	*		Power not on line during day.
							934	"	Top	"	—	*		
							937	"	"	"	—	*		
							909	B	"	"	—	*		
							912	"	"	"	—	*		
							915	"	"	"	—	*		
							918	C	W-side	"	None	*		Pole 918 burned by lightning.
							931	"	E-"	"	Br.	*		
7/13	9:30–11 p.m.			Heavy	0.36	53								
7/14–15	8:30 p.m.–1 a.m.	Near p.h.		"	2.76	20	60	B	Top	"	—	*	12 hrs.	Telephone not disturbed.
							72	"	"	"	—	*		
7/19	1 a.m.	Dist. to E.			0.36	20								
8/1	1:30–2 a.m.	Dist. to W.			0.22	46								
8/4	5:30–7.30 p.m.	Dist.			1.39	27								
8/6	2 a.m.	Dist.			0.0	21								

Date	time	Location	Direction	Lightning	In. of rain	Wind max. m.p.h.	Pole	Ph.	Loc.	Pin	Brace	Insulation damage	Duration of interruption	Remarks.
8/6	1:30–3 p.m.			Heavy	0.04		1028	A	Top	Gr.	—	★	25 hrs.	
							1065	"	"	Not	—	✱		Lightningrodonpole
							1067	"	"	Gr.	—	✱		" " " "
							1070	"	"	"	—	✱		
							1150	B	E-side	"	Br.	✱		
							1111	C	Top	"	—	✱		
							1135	"	"	"	—	✱		
							1138	"	"	"	—	✱		
							1141	"	"	"	—	✱		
							1144	"	"	"	—	✱		
8/8	12:30–1:30 a.m.	Dist.			0.16	24							None	
8/15	6:30–8 p.m.	Minneapolis to p.h.	Parallel to line	Heavy	0.76	40							"	Heavy line disturbances.
8/18	7:30–12 p.m.	Minneapolis to p.h.	Parallel to line	Very hvy.	2.26	62	1332	A	E-side	Gr.	Br.	✱	20 hrs.	
							1335	"	"	"	"	✱		
							1341	"	"	"	"	✱		
							1355	"	Top	Not	—	✱		
							1357	"	"	"	—	✱		Pole split.
							1351	B	W-side	"	Br.	✱		
							1357	"	"	"	None	✱		
							1350	C	E-side	"	Br.	✱		
							1351	"	"	"	None	✱		
							1387	"	"	Gr.	—	✱		
9/6	7:30–9 p.m.	E. of Minn.		Heavy	0.16	25							None	
9/15	4:30–5 p.m. and 7–8 p.m.			"	0.32	19							P. h. breaker opened by horns	Between Sept. 15 and 23 breakers at p.h. opened 9 times by operation of p.h. horn arresters which were set at too low a discharge point.
9/16	1:30–2 a.m.			"	0.38	25								
9/17	3:30–4:30 a.m.				0.22	38							P.h. breaker opened; no horn discharge.	
9/18	4–5:30 p.m.				0.01	36								
9/19	8 p.m. all night				2.98	38							P.h. breaker opened twice by horn.	
9/22	6:30–7:30 p.m.				0.05	28							P.h. breaker opened by horn	
9/23	5:30 p.m.	No storm.											P.h. breaker opened by horn.	
9/24	1:45 a.m.	" "											12 hrs.	Line choke coil grounded.
10/1	12 m.	Dist. Ltg.			0.63	27								
10/3	4 a.m.	" "			0.15	27								

Abbreviations and Symbols.

Ph. = Phase A, B, or C.
Loc = Location on pole.
Br. = Brace side.
P.h. = Power house.
None = Not brace side.
Gr. or Not = Insulator pin grounded or not.
✱ = Insulator shattered.
★ = Insulator punctured.

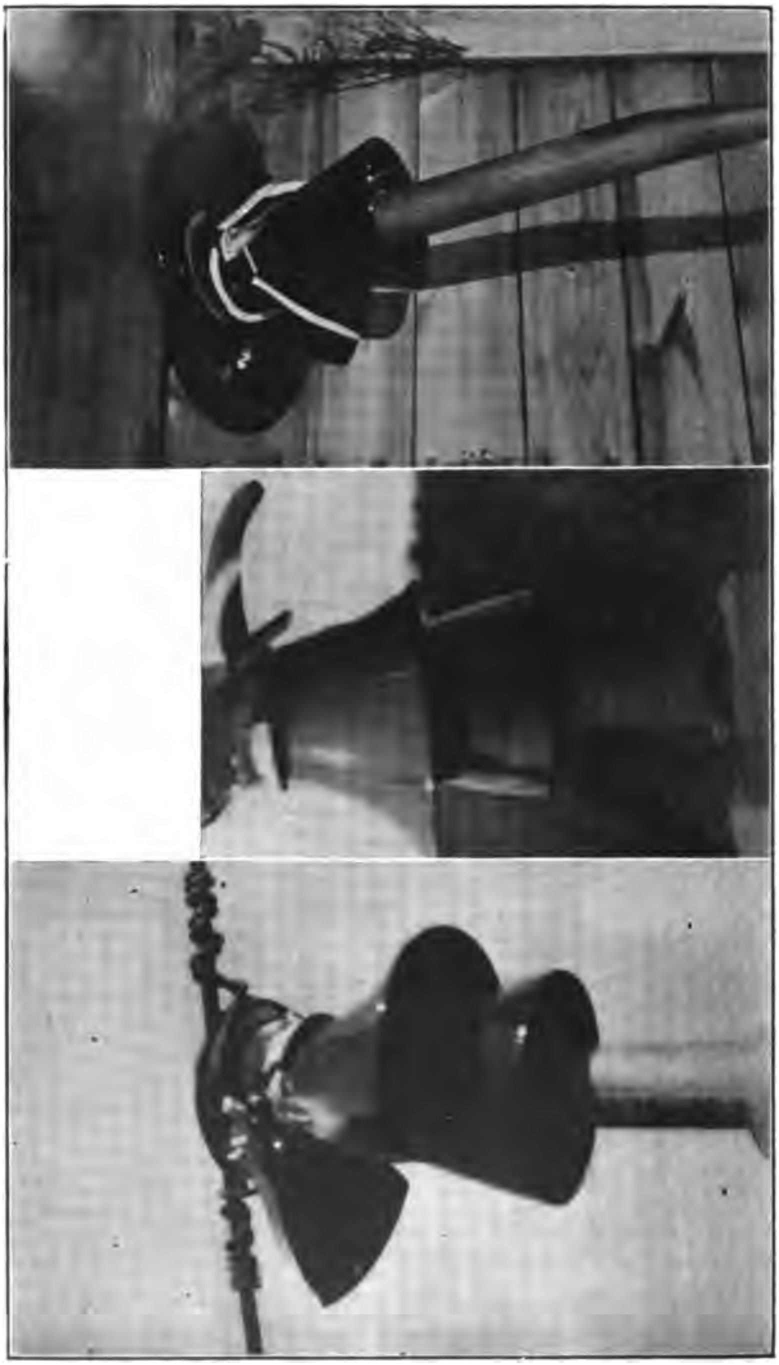


FIG. 9—Damaged insulators

Graphic records of tell-tale papers. The graphic records of tell-tale papers show in the form of curves (Figs. 11 and 12 and Appendix) the relative stresses on and discharges over insulators, or through arresters throughout the system, for the full storm series of the season comparing the action of various protective devices storm by storm.

The ordinates of the curves represent the relative size of puncture of tell-tale papers, the scale being so selected as to show as nearly as practicable the relative activity at each point on the line. Curves *A*, *B*, and *C* (Fig. 11) refer to the tell-tale papers placed in the grounds of the insulator pins on the corresponding phases and the fourth curve " Sp ." to the papers in the grounds of the protective devices. The relation of phases and transposition points, locations of special protective devices, choke-coils, pole numbers, etc., are shown at the top of the sheet. The columns to the right refer to the papers in the various types of arresters and give data for each storm. The curves on enlarged chart (Fig. 12) show the sum of the diameters of punctures for the three phases, and the corresponding punctures for the protective device grounds. In the preparation of these charts the tell-tale papers have been interpreted as follows:

Puncture, honeycombing, or discoloration of tell-tale papers, without blistering indicates quiet static discharge or static stress, as from the condenser action of the line and insulators, shown on chart by light line in curves *A*, *B*, and *C* (Fig. 11) and by " *S* " on the arrester records.

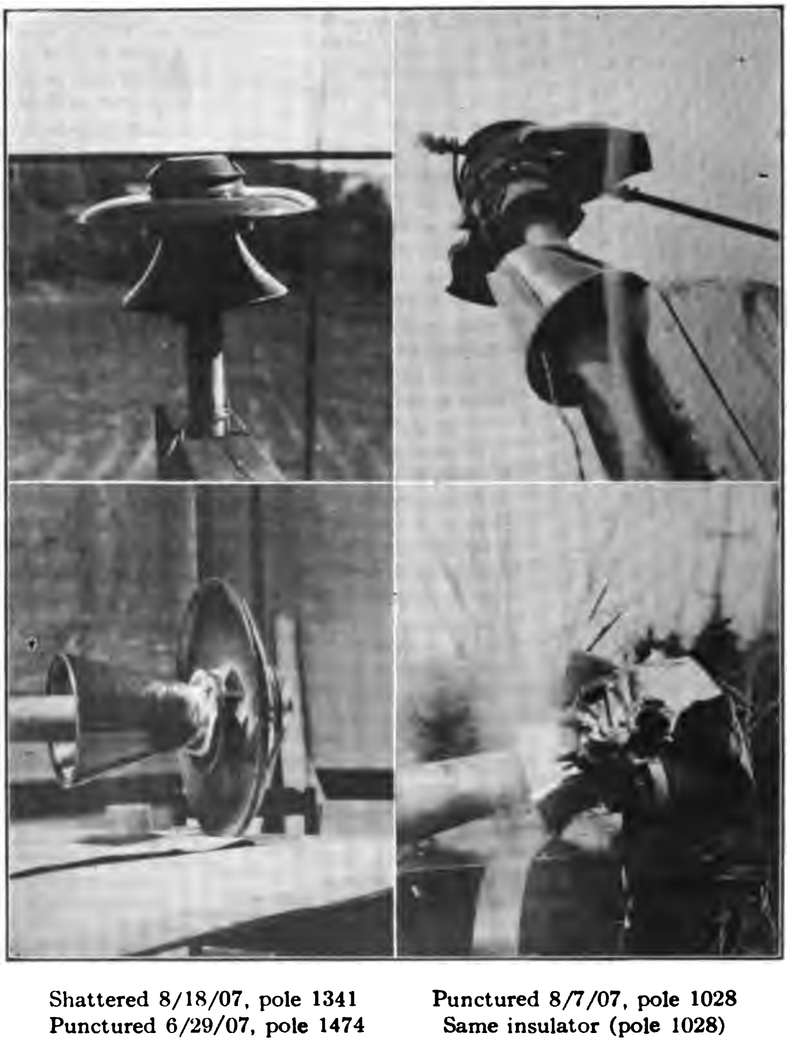
Blistering, that is, bursting apart of laminations of tell-tale papers or tearing of papers, without burning, indicates a disruptive static discharge, shown by heavy line in curves and " *O* " (Fig. 11).

Burning of puncture indicates dynamic current, shown by solid curve and " *O* " (Fig. 11).

Data from Operating Reports of 1907.

Storm, May 12–13, 9 *p.m. to* 6 *a.m.* Sub-station transformer bushing grounded. Telephone wires at sub-station burned off. Top insulator pole 1532 Ph. " *C* ", 4.5 miles from sub-station shattered, one side of all petticoats being broken. Current leaking to grounded pin slowly burning pole. No interruption until current off for repairs 19 hours later.

Storm, June 22–23, 9:30 *p.m. to* 1 *a.m.* Pole 1571 reported burning at 11 p.m. 11:30 to 12 p.m. surges on power house instruments and heavy discharges over static dischargers on low-tension side of transformers, burning out one set of dischargers. Breakers thrown out, then line cleared up. Pole 1571 reported



Shattered 8/18/07, pole 1341 — Punctured 8/7/07, pole 1028
Punctured 6/29/07, pole 1474 — Same insulator (pole 1028)
FIG. 10 showing fused puncture

still burning at 12:30, grounded line. Double arms burned off by wire dropping from broken insulator. Pin ground wire across line and telephone wires, making the telephone alive.

Pole badly burned, necessitating renewal. Telephone in order after clearing wires. When spillover at pole 1571 Ph. "*A*" pin ground fused off. Sub-station cell-type arrester active on Ph. "B" and "C". Low-equivalent arrester inactive. Service interrupted by switching operations after trouble only. Line out for repairs 18 hours.

Storm, June 29, 12 *to* 6 *a.m.* Side insulators poles 1474 and 1478 "B" punctured and broken. No interruption until repairs June 30. Telephone out. Station arresters inactive.

Storm, June 30, 12 to 8 *a.m.* Top insulators shattered on towers 224, 288, and poles 193 and 207 Ph. "A"; pole 193 Ph. "B"; and tower 224 and poles 172 and 208 Ph. "C"; P.H. horn arrester discharged on Ph. "B", arc breaking in two to three seconds without any disturbance to synchronous apparatus. Short-circuit one hour later.

Storm, July 4, 10:30 *a.m. to* 12:30 *p.m.* Current not on line after 4 a.m. Insulators shattered on poles 918, 934, 937, Ph. "A"; 909, 912, 915 Ph. "B"; and 918, 931 Ph. "C". Pole 918 burned off two feet below cross-arm. Pole set on fire by lightning as no line current was on. Line tested and found short-circuited at 1 p.m. Line put in operation 7:25 a.m. July 5. Most of damage on unprotected section between overhead ground wires types "A" and "B".

Storm, July 14–15, 8:30 *p.m. to* 1 *a.m.* Near power house. Insulators shattered on poles 60 and 72 Ph. "B" shutting down station for 12 hrs. Power house static dischargers burned somewhat. Power house horn arrester operated once. Telephone not affected.

Storm, Aug. 6, 1:30 *to* 3 *p.m.* Nine insulators shattered on poles 1065, 1067, 1070 Ph. "A"; 1150, Ph. "B", 1111, 1135, 1138, 1141, 1144, Ph. "C". Insulator punctured pole 1028, Ph. "A". Fused through all four parts and several minor punctures. Hugo horn arrester slightly active Ph. "A"; others inactive. Cell-type arrester discharged Ph. "A" and "B". Sub-station low-equivalent arresters discharged Ph. "C". Line out 25 hours.

Storm, August 18, 7:30 *to* 12 *p.m.* Most severe storm for several years. Lightning practically incessant. Heavy short-circuit on line at 8 p.m.; recovered for few minutes, then permanently out. Pole 1357, from which ground wires had been removed, split from top to below cross-arm where guy was attached. Top insulator shattered. Nine other insulators shattered on poles 1332, 1335, 1341, 1355, 1357, Ph. " A "· 1350, 1351, 1357, Ph. " B "; and 1351, 1387, Ph. " C ". Six of these were in sections where pin grounds had been removed. No evidence of short-circuits on any poles. Papers in line choke-coils on pole 1356 burned up and cylinders burned. Choke-coil on 1615 Ph. " A " paper blistered. Beside spillovers between 1300 and 1400, several between 800 and 950, but without damage. Other spillovers on 300, 353, 408, 563, 1034, and 1254 without damage.

Storms, September 15–42. Several of these were severe. Transmission line put out of service 9 times in 9 days. Six of these caused by power house horn arrester discharging, opening breakers. Arc held on horn tips, and in one case followed up lead toward tower, drawing an arc 20 to 30 ft. long. Probable cause, wind. Action of horns much more severe than with wider setting during earlier part of season. No damage from lightning.

Analysis of Records

Examination of the plan and profile (Fig. 8) indicates that:

Points where the line was especially liable to damage are, first, exposed heights and, next, wet bottom lands.

Damage was usually concentrated within a distance of a mile or two, with the exception of the two storms of June 30 and August 6, in the latter of which the storm crossed the line at a slight angle; and in the former, although there is no record of the direction of travel of the storm, there are indications that it traveled along the line for some distance.

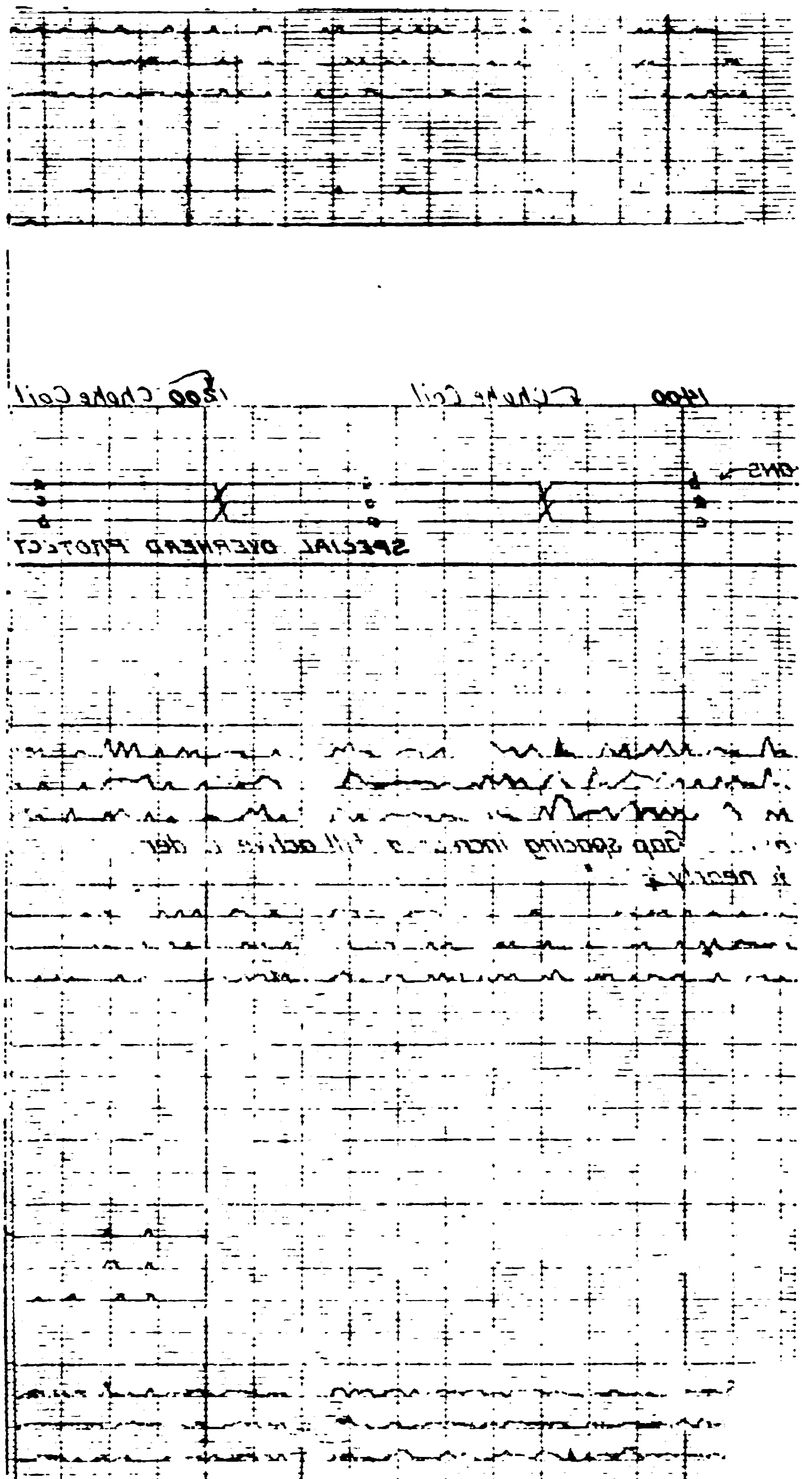
Thus far, trouble has not been confined to any defined points on the line, but as yet there is insufficient conclusive evidence on this point.

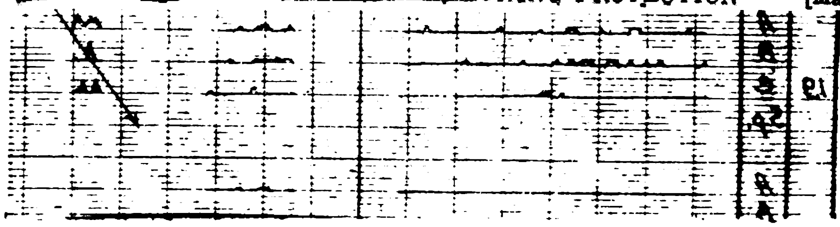
The tabulation of line failures appears to show that:

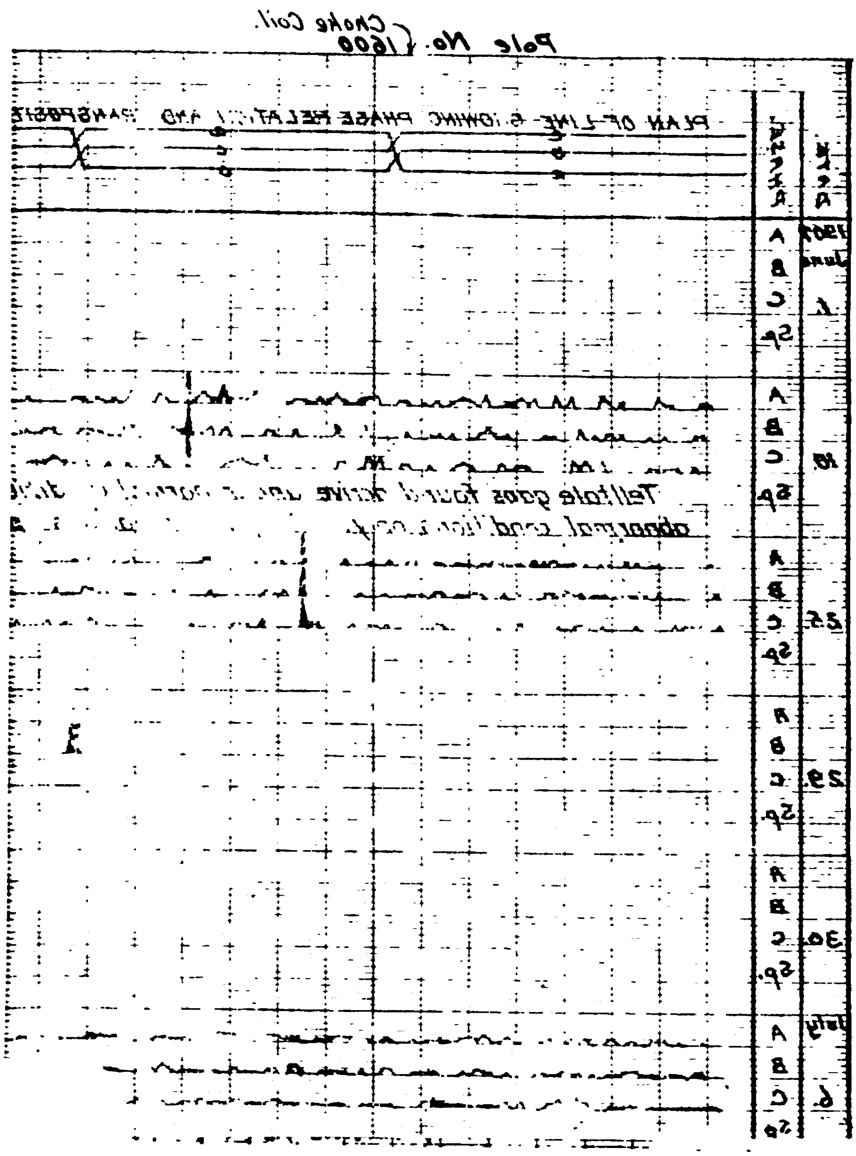
Where grounded and ungrounded pins came on adjacent poles, damage to the insulators generally occurred at the grounded pin, but the damage of a group of insulators on a section of line where all grounds had been removed and on pole 1065 indicates that grounding the pins probably did not materially increase the danger of damage.

Top insulators are somewhat more liable to damage than those on the sides and those on the brace side are apparently somewhat more affected than those on the opposite side.

Overhead grounded wire construction materially protects







insulators. The lightning-rods do not seem to have much effect except in cases of direct stroke.

The one case of pole splitting was a pole with no ground connection.

Examination of the tell-tale papers and graphic charts (Appendix and Fig. 11) indicates that:

Storms follow no well-defined paths, nor are their effects confined to any particular part of the line.

Stresses do not occur at any definite points.

Principal disturbances are due to immense static charges on the line in the immediate vicinity of storms. These charges are of great intensity and concentration, frequently spilling over a number of insulators without traveling along the line more than a few hundred feet.

The disturbances are confined to areas extending from one-half to two miles along the line, excepting where storms are traveling parallel to the line, as in the storm of August 18, which suggests recurrent and decreasing activity as the storm passes down the line. Even in this case no area of disturbance was over three miles in length.

In general, the protected nine-mile zone shows an appreciable decrease of insulator stress, activity of devices for distant storms and a very decided shielding effect of overhead grounded wires as well.

By following the curves for each type of grounded wire down through the season on the large graphic chart, Fig. 11, the activity of the grounded wires and the corresponding smoothing out of stresses on the insulators appear pronounced and consistent, with the possible exception of the storm of August 18, which was of unusual severity and traveling parallel to the line, so that charges may have been induced on the unprotected lengths of line between the protected sections of sufficient volume to spread out through the protected sections. A study of the enlarged chart, however, shows pronounced shielding effect even for this storm. The shielding action is especially well shown in the plot for the heavy storm of July 4, which occurred when the line was dead. This storm in traveling parallel to the line from southwest to northeast would naturally affect the unprotected sections of the line between the shielded sections. The chart shows how the shielding effect at the west ends of the short protected sections is counteracted by charges evidently coming on to the unprotected line as the storm approaches each protected section and how it prevents the reestablishment of the charge for some distance into the unprotected sections at the opposite ends.

Although more damage was done to the top and east or brace side insulators, in general the stresses appear greater on the west side, which in this case was toward the approach of the storm.

The effectiveness of the various types of overhead grounded wire appears to be in proportion to their theoretical value, the wires well above the line being the best and the wire in the center of the delta the worst. The activity of the lightning-rods, especially those at the side of the line, is marked. In this same storm, one of type "B" rods passed off a discharge which can be accounted for only by discharge between cloud and ground. This is of especial interest, as a lightning flash photographed by one of the inspectors the previous season showed ramifications apparently covering a territory a mile or two in diameter, emphasizing the necessity for some such protection.* This pole may have received a branch of such a direct stroke and in any case shielded the line from any unusual stress at that point.

The station arrester records on the graphic chart show the low-equivalent type of arresters to have operated according to their theoretical design; but whether the volume discharged was sufficient to keep down dangerous potentials is not certain, since in each important case the simultaneous and vigorous operation of the power house horn arrester outside the station indicated that it took the brunt of the discharge. The cell-type arrester was apparently more sensitive and operated more freely than the other types. There is no record, however, to show its action in disposing of abnormally heavy discharges. On the other hand, it appeared to be more sensitive in responding to strains due to a grounded line, and discharged for considerable periods under this condition without damage. The operation of the horn arresters, especially at the power house has been very promising and appears to fulfil their intended function as an emergency device. Their operation has been chiefly when the line was grounded by the failure of an insulator, but there is one case where the power house horn arrester discharged over both gaps in series without any indication of discharge through the water shunt of the second horn; this indicates

* See TRANSACTIONS A. I. E. E., Vol. XXV., p. 901 to 926.

that it passed off a high-frequency static discharge without allowing the line current to follow. But this single case is not conclusive. There are other cases, however, which show the passage of heavy disruptive discharges which indicate that these types have handled high-frequency disturbances as well as low-frequency surges. From their action so far it is believed that the two and three-gap types of horn arresters will be effective in handling occasional disturbances whether static or dynamic which might otherwise be of too great magnitude for the station arresters to dissipate, and that this can be done with settings which will not interrupt the line nor necessarily disturb synchronous apparatus.

The telephone line ordinarily operated quietly, but, although often too noisy to use in case of line trouble, it was, as a rule, kept from damage by the protectors and recovered when the line cleared up. The effectiveness of the protectors was well illustrated during a ground on one phase by the immediate burning out of two instruments not protected, while a protector on the third instrument discharged freely with no damage to the instrument.

Conclusions

The results of the Taylors Falls experiments so far indicate that:

The principal trouble is from temporary or permanent breakdown of line insulation by static charges induced in the line by passing storms.

Direct strokes between cloud and ground may occur at any time. Although there were several cases of damage so caused during construction, the first season's operation gives evidence of only one case and that without damage.

The induced charges are highly concentrated, and often of immense volume and intensity, discharging to ground over insulators with a disruptive effect that tends to shatter, but rarely to puncture them, often without line current following. Line current may or may not follow these discharges; if it follows, it may only temporarily ground or short-circuit the line.

Arcs established by insulator spillovers or leakage of charging current through damaged insulators may burn pole structures or further damage insulators and even fuse the line wire.

Such disturbances may occur anwhere on the line, but with a preference for exposed heights and to a less degree to wet lowlands.

There is no evidence of surges other than the direct effects of grounds or short-circuits, nor of stress at any definite points on the line such as from reflected or standing waves.

Top insulators, and to a less extent those on the cross-arm-

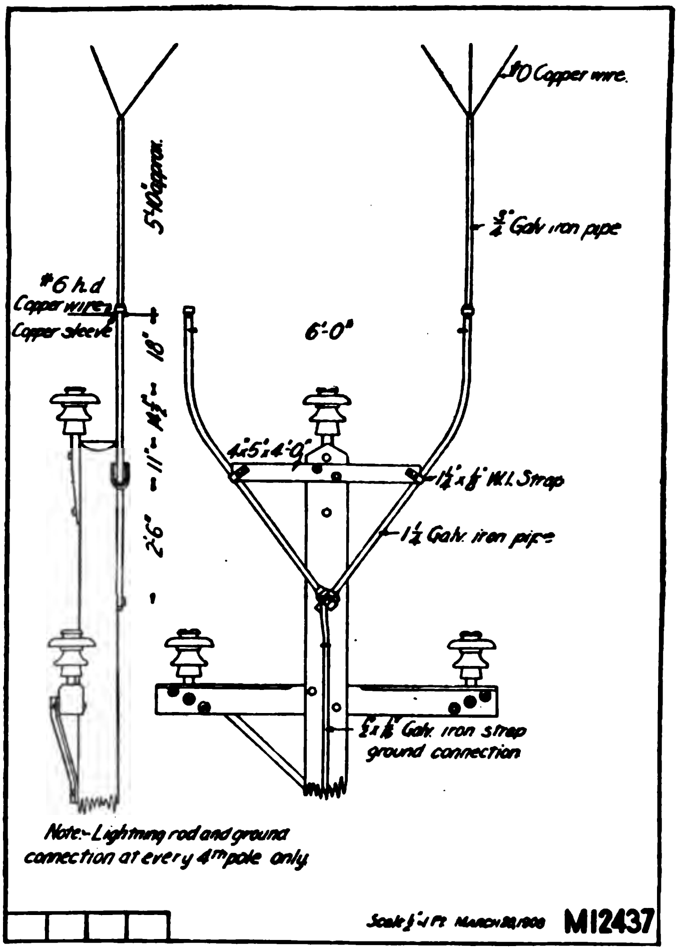


FIG. 13

brace side of the pole, apparently are more liable to damage, although the cases are not sufficiently frequent to be conclusive.

Grounding of insulator pins by tower structures or otherwise has comparatively little effect in assisting insulator breakdowns.

Overhead grounded wires are of decided value in shielding the

Date In 6-29-07
Date out 7-11

TAYLORS FALLS TRANS.

Date In 6-29-07
Date out 7-11
B TAYLORS FALLS TRANS.

Storm of July 4, 1907

7

Line #I
Leg. C
Station St Croix
REMARKS (see over)
Date in 6/30-07
" out 7-6-07

Line
Leg. C
Station St Croix

Line *Lum*

Leg. *1*

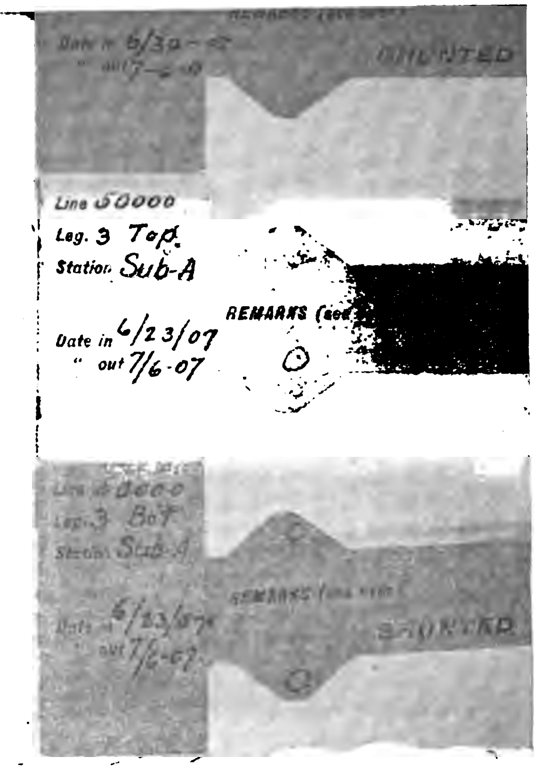
Station *Sub A*

Date in *6/20/07*

" out *7/6-07*

REMARKS (see over)

SERIES



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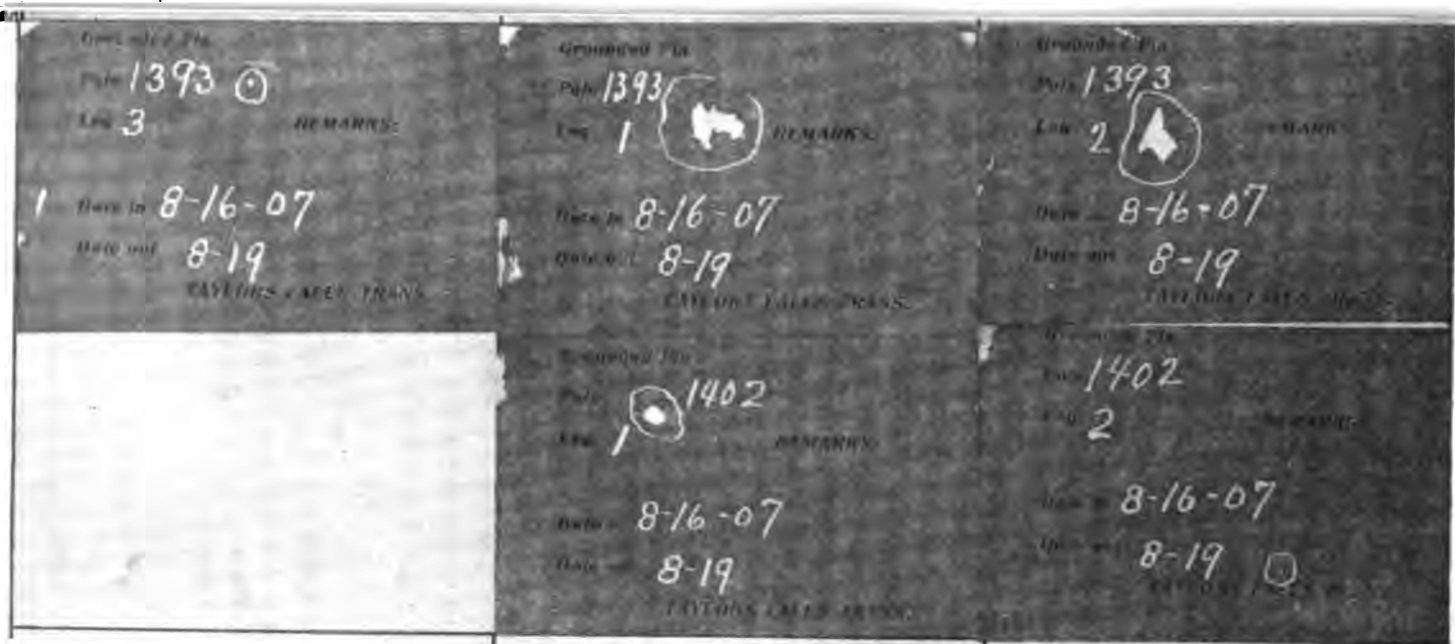

Storm of Aug. 18, 1907.

Pole

5

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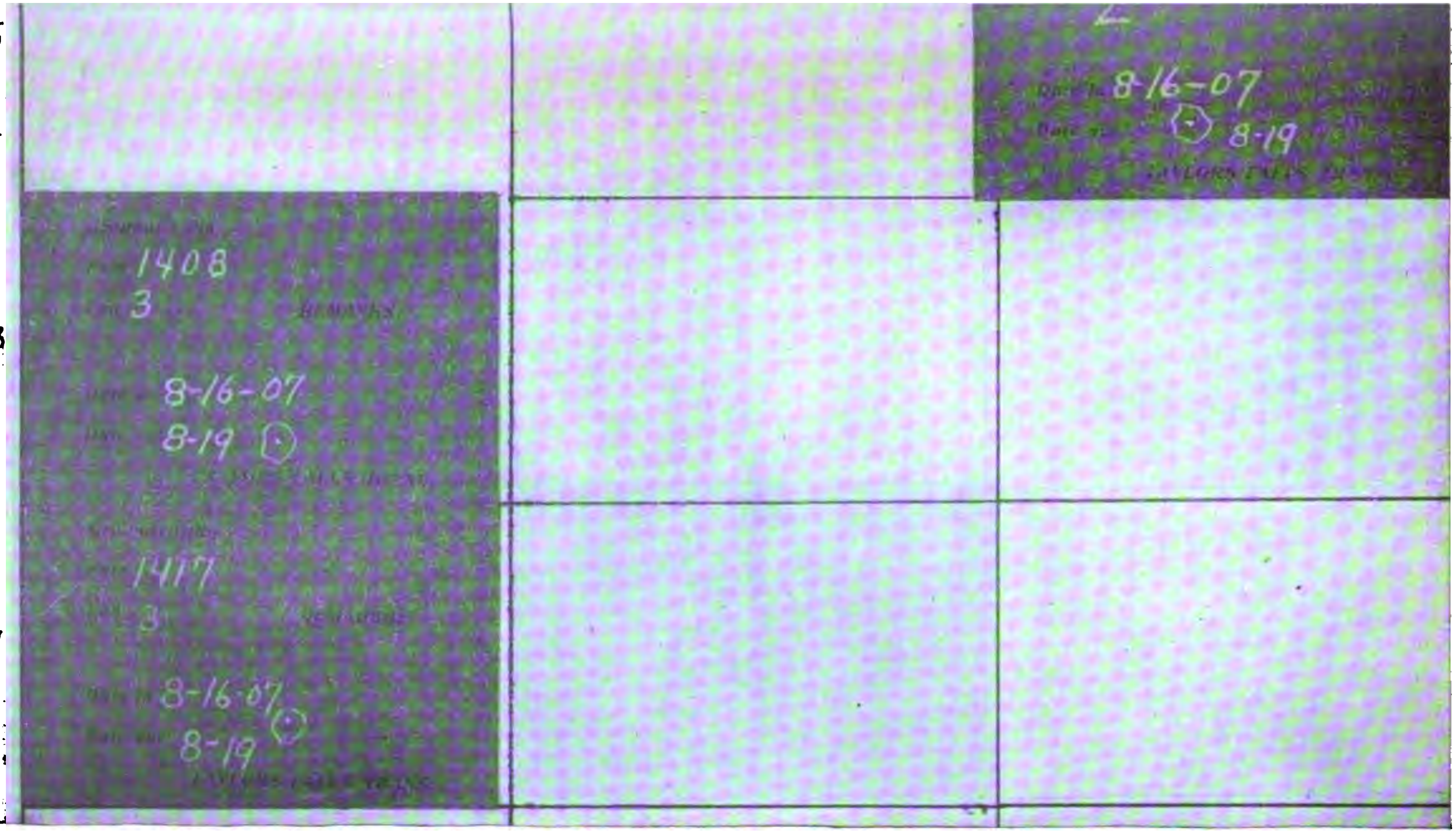
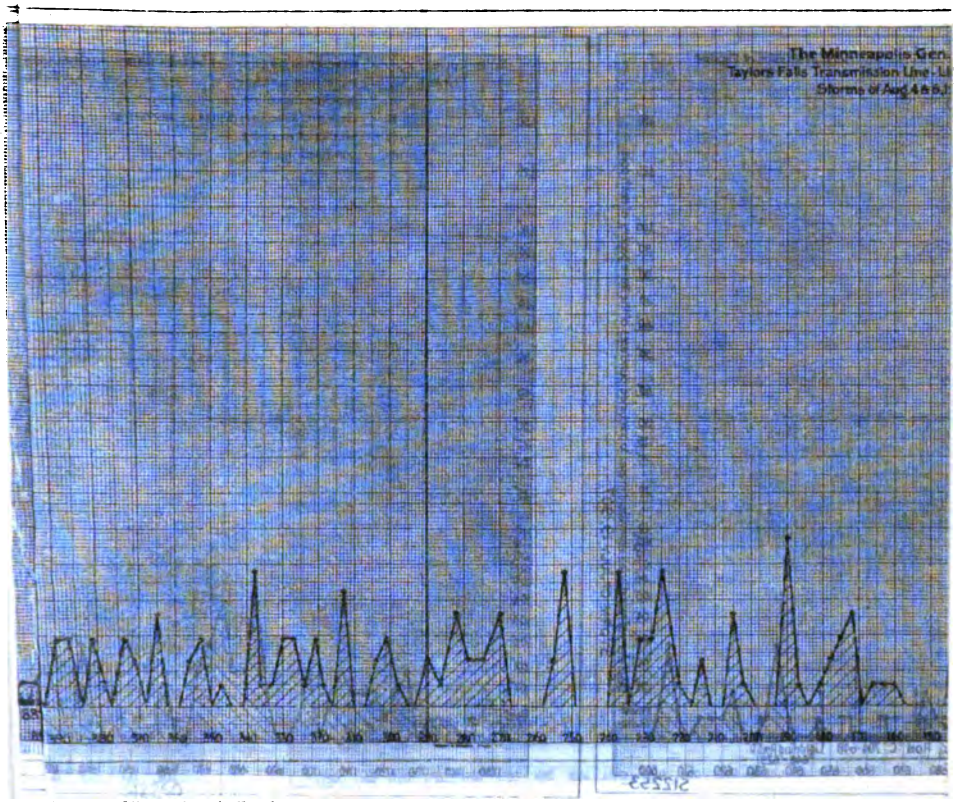
1417

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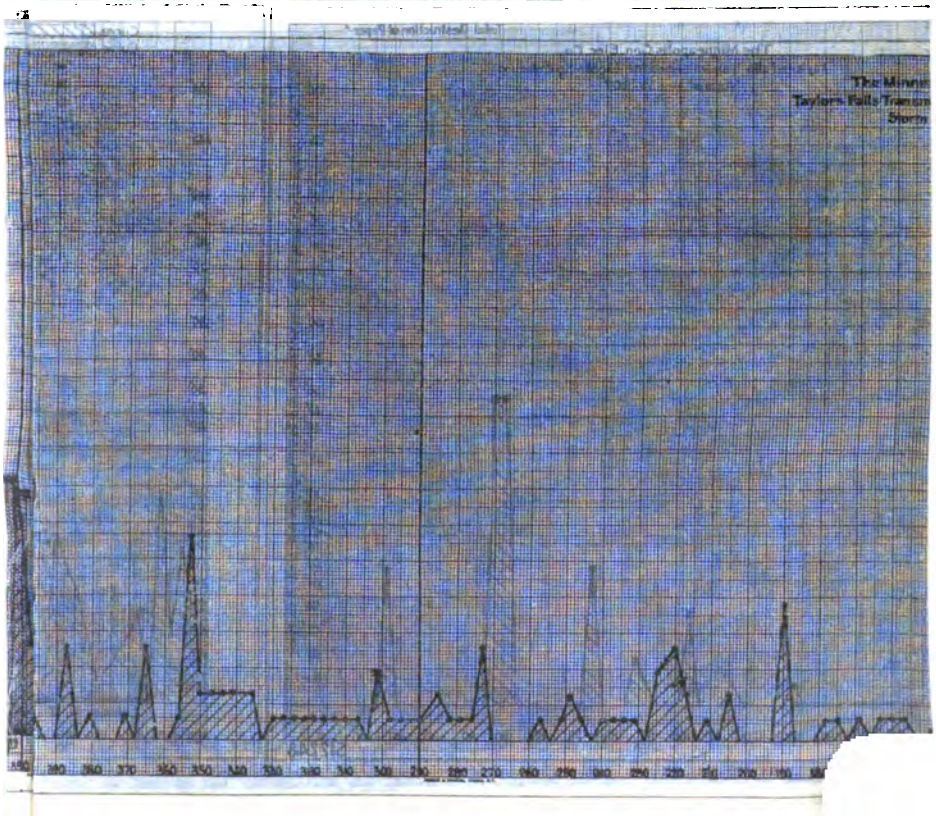
Storms of Aug 4 & 5
S12253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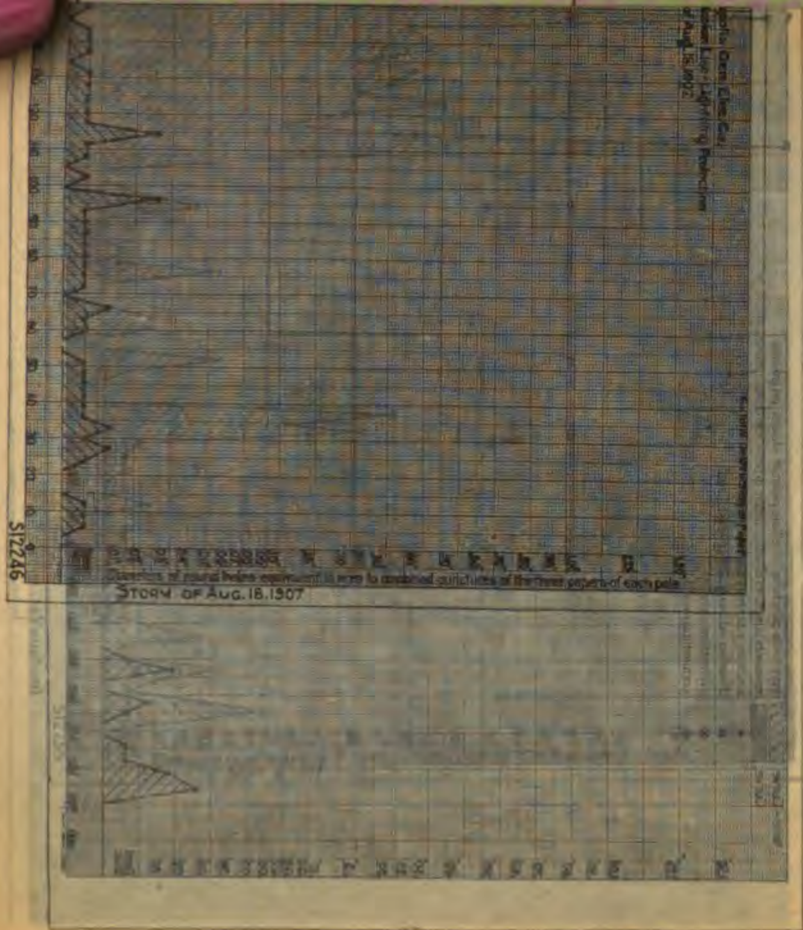
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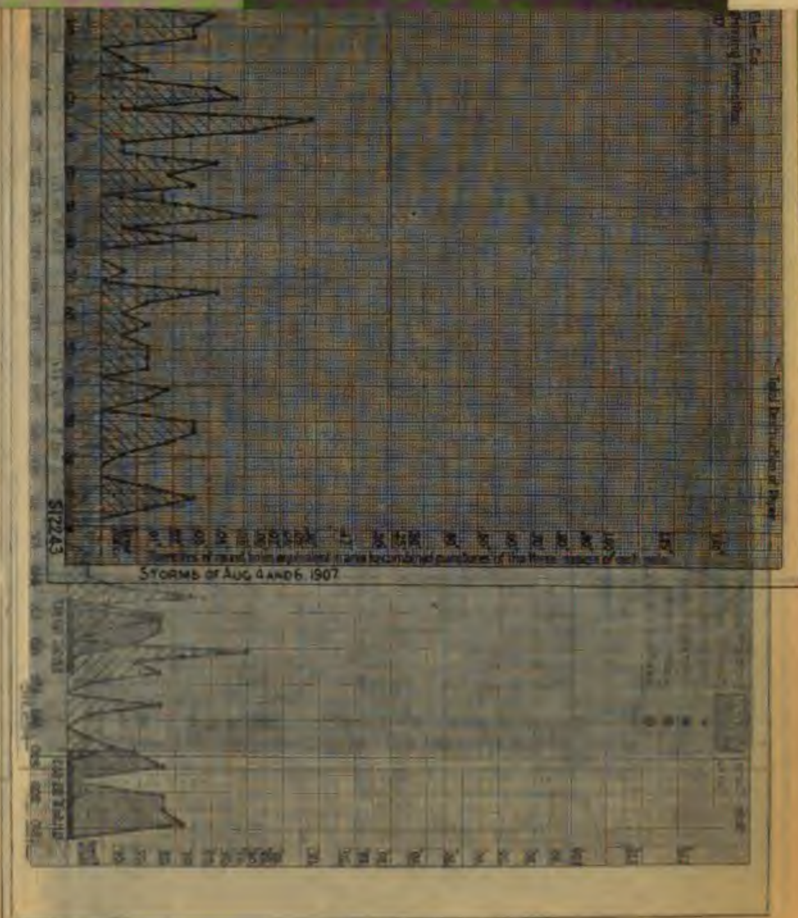

Total Destruction of Paper
Storms of Aug 4 and 6. 1907
S12243

line from induced static charges and in preventing insulator breakdowns.

In the only case of direct stroke, the lightning-rod pole alongside the line was effective in preventing line damage.

A grounded conductor running down the pole is of decided value in preventing splintering of the pole.

The selective resistance, multigap type of arrester is effective in disposing of ordinary disturbances.

The aluminum cell-type arrester is, in general, more sensitive and freer in discharge; it gives great promise for station protection.

Horn arresters of the series gap and selective resistance type are fairly sensitive to static discharge as well as to disturbances of lower periodicity, and of special value as emergency devices to relieve the station arresters in case of abnormal discharge. They may be adjusted to be fairly sensitive without interrupting service or necessarily throwing out synchronous apparatus.

The use of the tell-tale-paper system is essential in following the action of station protective apparatus, and is of decided value in studying line stresses and the effectiveness of protective devices.

The results of the above experiments have led to the recommendation that the overhead grounded wire construction (Fig. 13) be immediately extended about 15 miles in sections covering both ends and the more exposed parts of the line; that the use of horn arresters be continued and further adjustments studied; that the rest of the station and line protective apparatus be left as it is; and that the present system of tell-tale paper and other records be continued during the coming season.

A paper presented at the annual meeting of the American Institute of Electrical Engineers, New York, May 19, 1908.

STUDIES IN LIGHTNING PERFORMANCE, SEASON 1907

BY N. J. NEALL

It is intended to discuss in this paper the general import to high-tension transmission of the data gained in 1907 as to lightning performance on the Taylor's Falls line, 50,000 volts, of the Minneapolis General Electric Co., and on the Presumpscot Electric Company feeders supplying power at 11,000 volts to the Cumberland Mills, near Portland, Me.

By reference to the description of the Taylor's Falls situation given by J. F. Vaughan, it will be obvious that in this case *line* disturbances chiefly are being combated; whereas, in the case of the Cumberland Mills, *station* disturbances have demanded attention.

These two classes of lightning disturbance will be considered separately in this paper.

Line Disturbances

Lightning disturbances to a long-distance transmission line may be due to an induced (bound charge on the line) direct stroke, or both.

Bound charge. This idea embodies the well known principles of the operation of a static charge imparted to any insulated body. When this charge is gathered from an electrophorous in demonstrating elementary principles of electricity, the amount of charge, its potential, rate of accumulation, and rate of leakage, are, certainly of small values compared with those, at least, that we consider in electrical engineering to-day, not to speak of what we imagine the magnitudes to be in lightning phenomena.

A modern high-voltage transmission line must be highly insulated from ground at every point: for 60,000-volt service, therefore, it is easily conceivable that, in general, a tremendous electric charge can accumulate on the lines—assuming of course perfect equipment—and be held there with relatively small leakage. When in such a case as bound charge release takes place from the line, due to the discharge to ground, or to another cloud from the exciting cloud, an enormous rush of discharge undoubtedly follows the first point of breakdown to earth. Now since this discharge may be well extended beyond the point of maximum strain, there is relatively a considerable *flow*, once the discharge begins. This flow can be conceived as taking place over a wide area, changing from a sudden or explosive character at the centre of the strain area to a gently quiet one at the more remote points.

Theoretically, there are no ready means of determining how great such an area might be; it depends on a variety of conditions, such as extent of clouds, the degree of their electrification, their direction and rate of travel, etc. Practically on the Taylor's Falls Line it has been shown that they may be as great as several miles in extent of line, or as short as 1000 feet, approximately. From the operator's standpoint, the worst these clouds can do, or at least the usual average, is the desired information.

It has been shown that all such charges, once they are free to move tend to travel in waves, the progress and amplitude depending on the resistance in their path. In a limited length of line it may be easily possible to have the wave travel the whole length of the conductors, and be reflected at the open ends. This has shown itself prominently and repeatedly in the overhead grounded wires section tested by the Stone & Webster Eng. Corp. (See paper by J. F. Vaughan).

The tendency of such charges to travel in the transmission line is undoubtedly retarded very much by the skin-effect of the conductors; in fact, at the moment of release of bound charge we may consider that the charge has the choice of dissipating itself in three ways—along the line wires, over the insulators, or both. If the insulation is particularly good the charge endeavors to travel along the conductors. Its natural rate of doing so would be very high, in consequence of which there is a constant compromise between impeded progress along the wires and tendency to discharge over the adjacent insulator to ground. When the latter occurs, the rate of discharge is also likely to be again *suddenly* changed, and this, together with the absence of any inductance in the discharge path, is probably why tell-tale papers in such paths of discharge show violently explosive punctures.

Effect of discharge. From the data presented by Mr. J. F. Vaughan it has been shown that such discharges can be very violent and yet not harm the insulator, or produce a short-circuit. It has also been indicated that the discharges can be apparently of considerable length (compare static machine sparks) and yet make but a very fine hole in a tell-tale paper inserted in the discharge circuit. The presence of a thin long arc, or spark, which would of course be most pronounced in the case of " slow discharge over a high voltage insulator, is then to be thought of as the detrimental factor in the failure of insulators from this cause.

Now, curiously enough, there is very little trouble reported from lines operating at lower potentials, even at potentials of 30,000 volts. If the theory advanced herein before as to the formation of static strains on a line holds true, then every electrical line must undoubtedly receive such strains. It is, then, an important question—why well extended low-voltage lines do not lose insulators more frequently? The answer is probably partly this: No line can take a charge much in excess of its maximum insulator arcing-over strength. The result is, therefore, that the higher voltage lines must handle a proportionately larger and higher potential static disturbance. The character of the insulators for this purpose, especially when one considers them as special forms of high-tension condensers, undoubtedly has a still further bearing on the damage resulting to the line. The tendency in high voltage insulator designs to form long " anticipatory " sparks and arcs is well known among insulator designers; this helps, therefore, to form a conducting path for the line voltage to produce grounds, short-circuits, or punctures, as the case may be.

Again the action of the insulator under simultaneous static discharges and line voltage may have an important bearing on such failure.

From the data gathered thus far from Taylors Falls Line I would conclude:

1. That a bound charge can be impressed on a transmission line, with an extent from approximately 1000 ft., perhaps less, to several miles.

2. That its presence at any particular spot cannot be predicted, and, save for well known locations established after years of

careful observations, must be expected at any part of the line.

3. That it may occur successively at a number of points on the line, provided the exciting storm-centre travels along the line, and that the line is long enough to meet the necessary lulls between disturbances, or recharging of the clouds.

4. That there is no measure as yet of its maximum magnitude, but there is reason to believe that this is very great.

5. That the better the insulation the greater the concentration, and consequent disturbance once the charge can start to ground.

6. That the size and shape of the insulator determine the character of the spark which passes to ground, and govern failure.

Direct stroke. The phenomena of spark-gap performance in measuring high voltages, or in discharging a static machine, may be profitably utilized in order to understand the action of direct strokes of lightning as they affect an electrical transmission line.

In order that a line may be struck at all it must lie directly in the region of greatest strain; that is, form one of the electrodes of the lightning spark-gap, the other being the distant cloud. As the strain gradually increases between the earth and the cloud, the poles of the transmission line simultaneously respond to the new conditions. Even though they are thought of as being partial insulators, this makes no difference in the preliminary stages of this phenomenon. At the same time the transmission wires are accumulating rapidly a heavy bound charge. As soon as the flash occurs, it may at first strike a pole directly, and only later take the path via the transmission wire over the insulator, once the escape to ground of the bound charge has thus paved the way.

Again, the flash may actually occur between the transmission wire and cloud, because in the gradual preliminary increase of potential strain the effect of the insulator, so far as the static equilibrium is concerned, is comparatively nullified. In either case the result is the same—shattered poles, if of wood, and perhaps shattered insulators.

Upon reflection, it is clear that the common expression, " to be struck by lightning ", is technically incorrect; for any terrestrial object that becomes an electrode for a lightning stroke, plays as strong a part as the complementary part of the exciting cloud. It is the behavior of the electrode when the spark passes that determines its resultant condition. To this may be ascribed the peeling off of the bark of a tree, shattered chimneys, etc., and may be conceived as effects of repulsion inherent in the articles themselves, either from electrical causes or excessive local overheating.

In the ordinary conception of direct strokes only one stroke is thought to pass between cloud and ground, but it is also known that direct strokes often consist of light branch strokes as well as the main stroke. Since, moreover, the line under strain presents a variety of points along which such discharges may play, it is easily conceivable that failure of the insulators may occur almost simultaneously in several adjacent parts of the line.

Photographic study of lightning flashes shows that it is apparently oscillatory, and there are in fact many strokes in an indefinitely short time, although the eye may see only one.

From the data at hand (Taylor's Falls) it appears that the *current* flowing at such times may be relatively small as compared with the lightning voltage. We then have on a grand scale a duplication of the static-machine sparks, and others of a similar nature.

The remaining primary disturbance is the discharge between cloud and cloud. If these are far enough away from the line the effect can be neglected, but owing to their generally low altitude such a discharge can either cause a release in the line of bound charges of opposite sign parallel thereto, or a secondary discharge between the clouds and line or ground as the case may be.

In either event the effect on the line is essentially the same as described in the preceding discussion, and may be either simple or complex; that is, at present, unless actually observed, it is impossible in some cases to tell exactly whether a transmission line disturbed by lightning has been affected by induced or direct stroke.

GENERAL

Effects of the nature of wireless waves. In addition to the conditions described in the foregoing paragraphs, there are undoubtedly minor disturbances created in the line by the action of the lightning discharge as a source of high-frequency waves which, reaching the line, are absorbed in a manner similar to that of a receiver in wireless telegraphy. This absorption may be more rapid than the line can dissipate, and the result is either a surge of " static ", or, even worse, a discharge to ground, by reason of the impedance of the line wires to the free travel of the waves.

The result is, therefore, the same as in the preceding case—the imposition of a high peak of static on the line which tries to seek a level of zero value by traveling off in either direction on the line.

Effects arising from inherent characteristics of line construction depending on:

a. Insulator characteristics. An insulator for high-tension service is a form of condenser made up of a number of condensers (petticoats) of larger capacity, placed in series between line and ground. The best interest of the designer is, therefore, so to apportion his parts as to insure a uniform distribution of strain best suited to the service required. When this is but poorly attained there occurs the well known failure of insulators on test by premature puncture of one of the parts.

In addition to the absolutely essential qualities of ruggedness, high-class dielectric strength, and good finish, an insulator for such service must have a strength against arcing over at normal frequency at certain values previously determined upon by the designer. In general, insulators are designed not to arc over at below twice the voltage of the system on which they are to be used when subjected simultaneously to some such rain test as 0.25 in. per min. driven against the insulator at an angle of 45°. This, so far as it imitates nature, is of course very severe, and gives for any design a much lower voltage of arcing over than would be obtained with the insulator dry.

In testing such insulators the usual practice is to raise the voltage fairly quickly until arcing over occurs; if this falls below the desired voltage the design must be changed. An insulator can, in general, stand a higher voltage thus administered than voltage applied continuously.

Some insulators are designed for large total lengths of surface to prevent leakage; and where this is not likely to be linked with severe lightning disturbances the design of the insulators can be made in a different way. It might be said, however, that the insulator thus designed is likely to make a poor showing under rain test, while it is not at all improbable that for all-round service the insulator well designed for lightning and rain may do well in the leakage class. It is not the purpose of this paper to consider the latter.

On the rain test at present, therefore, we look for characteristic performance. Two phenomena exhibit themselves: first, the static strain, or envelope of the insulator repulses the drops of falling rain away from itself; secondly, the combined forces of static repulsion and mechanical deflection of the falling rain give rise to a resultant direction of rain, which, if the inner petticoats are not properly shaped, throws the water directly under the top petticoat. In general this has been found to be most pronounced in curved petticoats and absent in straight parts when properly inclined. It is obvious that the former condition is very harmful to the strength of the insulator under high-potential strains. In addition to this, many insulators give evidence of internal unbalance long before breakdown. This usually means an insulator very liable to puncture.

So far as the insulator used on Taylor's Falls line is concerned, I wish to state that standard tests which I have made independently on this type show a satisfactory performance along the lines indicated in the preceding; this leads me to think that its characteristics are of distinct value in the lightning problem now under consideration.

Now the preceding characteristics apply entirely to insulator performance at *normal* or commercial frequencies. At higher frequencies there is as yet very little data, but the following ideas may be tentatively considered as an aid to the present discussion.

Equivalent spark gap. In testing insulators to date no consideration has been given to their equivalent spark gap. For very high voltage insulators this is hard to secure for the general want of adequate apparatus but, it is undoubtedly within the reach of some. The principle involved is this: that while an insulator may have a very good performance under normal frequencies, it may be very poor at high frequencies, or their equivalent.

Nature of discharge. It is not inconceivable that the discharge over an insula or may be tenuous as well as abrupt. If tenuous, the shape of the petticoats once again materially affects the disposition of the arc, and possibly causes a fracturing by means of the intense local heating and the consequent unequal expansion of the porcelain. There may also be "percussion" effects due to the sudden change of atmospheric pressure around the insulator at the time of arcing over, and thus fracture an insulator. These ideas are based on the characteristics of shattered insulators on the Taylors Falls Line.

Simultaneous static discharge with line voltage. This is the equivalent of static discharge over a lightning-arrester with voltage simultaneously present. In the case of insulator performance, the object of the investigation should be to determine the degree of non-arcing power of any given design under the conditions noted.

b. *Mechanical design.* The nature of the line construction, whether of wood, or entirely of metal, the length of span, size of insulator, number and nature of braces, etc., determines to a large extent the degree of damage any lightning disturbance will cause. If the poles are of wood, splintering of the poles may often occur, sufficiently, at that to require renewal of the support. Short spans naturally subject more poles to disturbance, within a given area, and, therefore, to more likelihood of damage. Large spans on metal towers invite more trouble (relatively at a given support) because of their isolation and attraction for the charge.

c. *Line profile and local topography.* Attention has long since been called to the relation between the topographical location of the line, and it vulnerability to lightning. In any layout of importance the profile, or cross-section of contour, should be made in order to show the maximum and minimum elevations and relations of hills to valleys in the iine. Where geological formations are known, the extra information thus given is of value in determining the probable points of discharge between cloud and ground, provided the general direction of a storm is also fairly well established. This feature has been demonstrated on the Taylor's Falls line by the apparently greater vulnerability of the west side of the line over the east, direction of storm from northwest to southeast. It is also thought that lightning has shown a preference for striking high elevations of the line and in damp, swampy places.

d. *Proximity of sub-stations.* It is just as possible for a lightning discharge to occur near a power station as not, in which event ordinary lightning protection would be heavily affected. It is doubtful whether any device now proposed for station protection, exclusive of horn lightning arrester without appreciable effective resistance in series, could handle successfully a release of heavy bound charge, etc. It is, therefore, important to insure adequate protection at such points. On the other hand, the tendency of line disturbances to concentrate might render any station immune if sufficiently remote therefrom. These conditions have been amply illustrated on the Taylor's Falls line.

METHODS OF PROTECTION

From the data given by this line, and on the basis of the preceding considerations, both theoretical and practical, the following methods of obtaining protection against line disturbances from lightning may be considered:

1. *Overhead grounded wire.* Judging alone from the data now at hand as to its behavior, an overhead grounded wire placed near the line conductors may be considered beneficial. Apparently, it is not necessary for the grounded wire to be above the transmission wires in order to absorb a certain portion of the static charge. This has been positively measured in the case of the grounded wire in the centre of the triangle on the Taylor's Falls Line, and is doubtless helpful in reducing the strain. Its limitations in this respect are obvious, especially when it comes to increasing the amount of ground wire protection over that given by one wire.

The ideal static protection, as is known, would be a metallic envelope for the line; but since this is not commercially feasible, it is thought possible to approximate it by supporting several grounded wires above the line. These wires are so placed with reference to the line wires that an imaginary plane, extending at an angle of 45° from the wire on either side of centre, will just pass over the transmission wire. There are as yet no positive data to show the value of this consideration, but there are data of a definite nature showing the effectiveness of the double-wire overhead grounded-wire protection.

When the possibility of simultaneous direct stroke is borne in mind, a further disadvantage of the grounded wire placed *within* the triangle is at once apparent; for a direct discharge between this wire and cloud is not easily conceivable, certainly not so conceivable as in the external arrangements of grounded wires where the possibility of divergence of direct stroke is better prepared for.

The experimental data on this performance have not yet fully and completely established the superiority of type, but there is certainly good reason to think that an overhead grounded wire protection, consisting of several wires supported above the line, is good protection. This protection should reduce the disturbance to the line to a very small amount indeed. In fact, the power of absorption shown by such protection leads to the conviction that if a transmission line were so equipped throughout, very little static disturbance would ever reach the stations;

in other words, the overhead grounded wire would not only shield against the line troubles, but reduce consequent station disturbances.

2. *Lightning-rods.* There is evidence to show the value of lightning-rods to a transmission line, particularly in that case of Taylor's Falls where a lightning-rod was struck and the telltale gaps on the line adjacent thereto showed no disturbance. This diverting power is certainly of value. Two methods of application are feasible, first, as an additional feature of line protection placed separately but adjacent to the line at points known to be particularly subject to this effect. Since the latter is at best uncertain, I prefer the inclusion of a lightning-rod with the overhead grounded protection at frequent intervals throughout the line. On a steel tower construction (solely because of the usually long spans) these should be placed on each tower; on a wood-pole line, one of these could be placed at each grounded pole. These rods should perhaps extend 4 ft. to 6 ft. above the overhead grounded wire, and end in spreading tips.

3. *Grounds.* The importance of good grounds for the overhead grounded wire is patent. Too great care cannot be exercised in this direction. The data given show that even on the grounded wire the passage of the charge to earth is apparently impeded, even by the short distance it had to travel along the line. For this reason it is clear that grounding at every hole is beneficial to the discharge. For ordinary line work time may prove that grounding every several poles is adequate, but that near stations or important points of the line, grounding at every pole is essential. This would be particularly desirable in the case of partial protection of the line where a stretch of overhead grounded wire was used to protect a sub-station. In this case the data as to the possible extent of such charges make two miles, approximately, the minimum limit of length out from the station that would secure nullification of any nearby induced disturbances.

4. *Extent of application.* It is an open question of economy whether to equip a line completely, or partially, with overhead devices; but in consideration of the charges which they may be called upon to carry *at any point,* the whole line protected is theoretically and generally the safer policy.

5. *Insulators.* The Taylor's Falls data show that while the overhead grounded wire appears to remove the greater part of

the stress, yet it should not be assumed that the remaining charge is negligible.

For this reason the selection of insulators for such a service should insist on as high quality as ever before. The criterion of approval should be a non-arcing at no less than double normal potential under rain test of 0.25 in. per min. at 45°, with pin grounded, or an equally severe test. Under such a test the insulator should be relatively free of premature arcs and sparks. No rain should be deflected under superposed petticoats, and thus promote breakdown. When possible the equivalent spark gap of the insulator should be determined, and should always be high, certainly giving a large margin over any standard lightning protective apparatus connected to the line.

The reason of this is patent from the performance of insulators on high-tension lines. It is clear that when the line is running with the neutral grounded the severity of service on the insulator because of the resulting short-circuit arc is certain to be quite destructive. In this respect the ungrounded system is better because the discharge over the insulator does not necessarily mean a short-circuit, or, if two insulators on opposite phases should simultaneously discharge, the resulting short-circuit may be favorably effected by the intervening resistance conditions involved.

The performance on the Taylor's Falls line brings out an important element of high-tension transmission line design; namely, the probable extra vulncrability of the insulators on all-steel towers, cross-arms, and pins. Where a section of wooden cross-arm intervenes between the insulator and the nearest ground it is possible to conceive of an increased arcing distance, which in the case of small insulators might be of some benefit in holding back disturbances. I therefore conclude:—If the insulator can be properly selected as to size, equivalent spark gap, arcing over voltage, and general characteristics, the nature of the tower construction may be neglected, particularly if overhead ground protection is present.

6. *Line choke-coils.* At the suggestion of Dr. C. P. Steinmetz, line choke-coils were originally included in the program of experimental equipment for Taylor's Falls Line, in order to determine by means of tell-tale gaps how far any given disturbance travelled along the line. The experiments from which these data were to be obtained were not carried out, but the choke-coil papers show that the coils operate freely under the static disturbances

which are now known to be present on the line. In consideration of the small inductance of these coils (1 ft. diameter by 20 turns, approximately 60 ft. of wire) the tell-tale indications of static rushes are most impressive.

The chief difficulty in such an equipment is in the construction of the choke-coil itself. For the Taylor's Falls line the coils were finally constructed of brass tubing, which has apparently been found reasonably satisfactory. It is yet too early to say whether such a feature can be of great benefit. The danger of such an equipment is the possible piling up of potential at the nearest insulator, and the consequent failure of the same.

7. *Horn lightning-arrester.* The horn lightning-arrester (essentially a simple spark gap of special form between line and ground) is, so to say, a hybrid—part station, part line device. In this paper it is considered solely as protection—extraordinary against great disturbances of any source reaching a sub-station or power house.

a. *Gaps.* I think it must be clear from even this one season's records on the Taylor's Falls Line that when a horn arrester is at the centre of a violent static disturbance, for example, a disturbance that affects the insulators, it will act as do the insulators—arcing freely over a large distance. In this way, by proper relative adjustment of the various gaps, severe disturbances near important points can be carried off without damage to either the insulator or the station apparatus. Judging from the magnitude of the static discharge as evidenced on some of the line tell-tale papers, it is a grave question whether standard station lightning-arresters could take care of anything like a nearby direct stroke. There is less doubt that the horn arrester could do so. In the case of grounding of the line, the horn gap will also operate, but in my judgment such action should be made as difficult as possible, in consideration of the sensitiveness of the electrolytic arrester to this effect. This leaves the horn arresters to care for emergency disturbances like a direct lightning stroke and high-power surges only.

On the Taylor's Falls plant there has been a pronounced evidence of the effectiveness of a number of gaps between line and ground operating on the selective path principle. In general the operation of the gaps has recorded both lightning disturbances and disturbed static balance from grounding of the system. In the former case all of the gaps between line and ground would operate, the tell-tale paper sometimes indicating a light discharge not followed by dynamo current, and again quite a heavy line current. The methods adopted apparently establish this action very well, irrespective of the arrangement of the resistances, whether directly in shunt as in the power house group, or directly in series, as at Hugo. The curious preference for the circuit through the fuse to ground at the power-house horn instead of from the shunt lead to ground—the resistance being relatively equal in all directions—shows forcibly the ease with which such disturbances take a long *air* path in preference to the regular circuits prepared for them.

b. *Resistance.* In the matter of resistances there are as yet incomplete data on the behavior of water, but certainly the operation of the last season did not exhibit any bad traits in this material. At the power house the water for the whole arrangement is supplied by the tailrace, and is, therefore, constantly renewed. Its resistance, however, is low. My fear was that a discharge to ground would go by way of the first path to shunt resistance, and thus directly to earth. I find, however, that it has apparently not done so, and I conclude that this is due partly to the superior character of the horn arrester " ground " reached through the fuse (see paper by J. F. Vaughan). The tanks at Hugo and at the sub-station have given no trouble. The amount of resistance best suited to the purpose is yet to be worked out. It may be that the size of receptacle employed, as well as the method of arranging electrodes,* has perhaps had an important bearing on this matter. The use of bituminized fibre conduit enables high insulation at the point of entrance of the leads, and controls the degree of electrode exposed in the water for the passage of the discharge.

c. *Operation.* In general, it must be borne in mind that if the horn is to carry any current, the *more* current it carries the better, so far as self-extinguishing power is concerned. This, however, is bad for the system, tending to pull out the breakers. The employment of light fuses so limits the discharge that protection is lacking where disturbances repeat themselves. The selective path multigap type of horn (gaps arranged in series as at Taylor's Falls and Hugo see paper by J. F. Vaughan) permits a better adjustment theoretically, to the variables of such disturbances, and insures less need of attention.

It is recognized that water resistances must be put out of commission in winter, unless special provision be made for

*This method was suggested to the author by Mr. John L. Harper.

keeping them warm. Where such apparatus is near a substation, this is not difficult. In such a situation as the middle of a long-distance transmission line it is still feasible but scarcely necessary. Since its chief use may here be considered in connection with lightning disturbances, there remains only the possibility of high-power surges which could be easily provided for by a proper adjustment of the horn gaps in series with a fuse. Even in this case a fuse might be retained of considerable current capacity, and depend solely on the gap action to relieve the strain.

It seems desirable to have the horns operate coördinately with the arcing over characteristics of the insulator. Since the grounding of the line may cause a momentary potential rise at some distant point, owing to the rush of line charging current to its new position of equilibrium, the setting of the first gap in a selective-path type should be approximately 150% normal voltage with reasonably high resistances. Too high resistance would impede the discharge. The total gaps in series should breakdown just under the arcing-over voltage of the insulators under its worst performance, usually taken to-day as at rain 0.25 in. per min., angle 45° with pin grounded. It were better with a single gap to have no resistance in series, only a fuse, to be set for the highest voltage.

These considerations are subject to change with increase in knowledge as to actual equivalent spark gaps of insulators, lightning-arresters, and horn air-gaps. It may be possible later to call for larger air-gaps, in the horns, because of its equivalent spark gap characteristics. The present ideas are recorded merely to illustrate the purposes and tendencies for the future in the Taylor's Falls installation.

A horn arrester should preferably not be called upon to operate on any condition which a standard station lightning-arrester could handle.

The bad effect of wind on the arc has been well indicated by both experiment and actual operation. This feature of horn lightning-arrester operation will always be a serious menace to a system at the time of simultaneous operation of two adajcent horns; it is a matter of chance which must be allowed, or elaborate preventive precautions must be taken.

8. *Special line-protection station.* The operation of the horn arrester group at Hugo (centre of the line) Taylor's Falls is critical in that it focuses the whole question of placing station type arresters on the line to draw off the static disturbances.

It is clear from the data now at hand as to the minimum area of local concentration of lightning line disturbances, approximately 1000 ft., that in order to do this fully a very large number of arresters (approximately six groups per mile) would have to be installed, and then, aside from the consideration of maintenance, there is the great question as to their reliability and sufficiency under the conditions. During the past season I have had a group of low-equivalent alternating-current lightning arresters, equipped besides with phase to phase protection, at the middle of a 11-mile, 11,000-volt line, in Maine, to assist in carrying off discharges from the line; for there has been considerable action at this plant from lightning. The characteristic of the performance of this system as a whole is a phase-to-phase operation, rather than from line to ground. Even though lightning storms were particularly frequent in this locality, and station protective apparatus at both the generating and step-down ends of the line operated freely, with considerable dynamic current manifested, the discharge at the centre of the line was nearly always lighter and colorless. To such a degree does this check the performance of the central arrester group on Taylor's Falls line, that I am inclined to conclude that for the majority of line disturbances, whether static or otherwise, a central group does little good. What a high-power surge would do is still an open question.

While these conclusions do not destroy, theoretically, former practice in regard to frequent placing of station arresters on the line, they seriously modify its practical value. By the theory advanced that the better the insulation of the line the more local the serious static disturbances will be, then line arrester stations decrease in value as the design voltage of the line increases. They thus become self-eliminating from our consideration.

9. *Miscellaneous.* So far as attempts have been made to protect against line disturbances by larger insulators, or special features at insulators, such as horns to modify the effect, it is clear there is no reduced interruption to service itself when discharges actually occur. For this reason I should prefer, where feasible, any protection scheme which aims to prevent the static disturbances getting on the line at all.

Station Disturbances.

The characteristics of this feature of lightning disturbance to electrical apparatus are too well known, and too fully discussed, to need further mention here. For the sake, however, of new corroborative data, which I now wish to offer, I will summarize the phenomena as follows:

1. Lightning effects causing line-to-ground disturbances.
2. Line-to-line disturbances.
3. High frequency (or equivalent) and low frequency.
4. Internal disturbances due to grounding of line, short-circuits, etc.

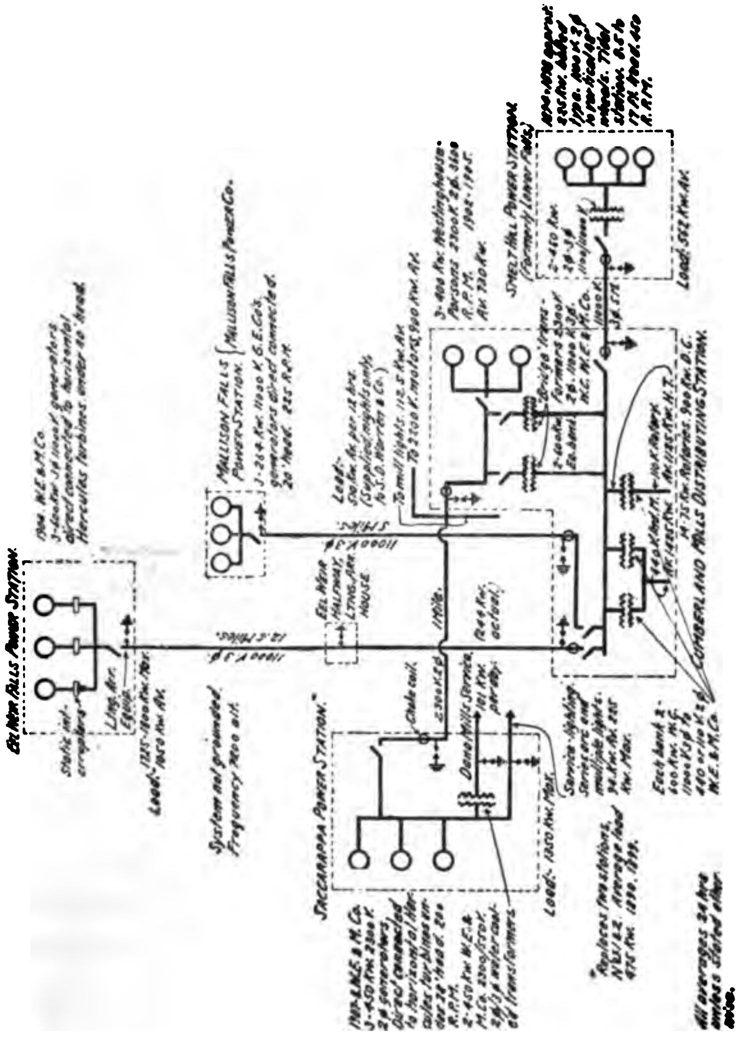
Line-to-ground. From the station data at Taylor's Falls power house, as well as from the Minneapolis sub-station, the frequent and full operation of all types of station protection is fully established. As has been stated by Vaughan, throughout the season of 1907 no apparatus was hurt by lightning, save in the case of one transformer bushing, which failed by grounding.

The lively operation of the apparatus, as evidenced by the action of the series and shunted gaps, respectively, and the heavy discharges over the electrolytics, indicate a considerable strain to ground, which for the present must be considered effectively handled by the protective apparatus.

The size of the punctures over the low-equivalent alternating-current arrester does not differ materially from similar data on apparatus for lower voltages. In consideration, however, of the data now at hand as to the action of static discharges on the line and the effect on tell-tale papers where free discharge occurs, there is a question whether or not station lightning protective apparatus must not be limited in action to reflected or transmitted disturbances of lesser magnitude, and to such disturbances as are generated in the system itself. Certainly, commercially we cannot expect more than this. Comparing the action of the various types, it has been shown that no arrester shunts the other entirely. Thus while from the response to ground the greater sensitiveness of the electrolytic is apparent, yet in case of greater severity all arresters operate.

I recognize that, theoretically, both types should operate at the same point, but in the case of the electrolytic arrester the possibility of a closer adjustment to circuit conditions without consequent short-circuit is greater than in the low equivalents or other multigap resistance types of arresters.

At the plant of the Presumpscot Electric Company, previously referred to, a large amount of experimenting has been carried on for the last two seasons, and is still under way. This plant consists of three hydroelectric stations feeding a central distribution station, (Fig. 1) where the power at lowered voltage is conveyed to a large synchronous converter load and induction-motor load respectively, one of the stations generating directly at 11,000 volts.



DIAGRAMATIC SKETCH OF TRANSMISSION LINES. PRESUMPSCOT ELECTRIC CO.

FIG. 1

In consideration of what appeared to be pronounced line to line characteristics each protective apparatus equipment on this system was supplied with extra gaps and fuses (until best adjustment should have been accomplished) and in one case low equivalent arresters were placed across the line. In addition to this the regular low-equivalent arresters between line and ground were shunted with gaps and fuses, two each, around the shunt and series resistances in series, (Fig. 2). The whole system was carefully equipped with tell-tale papers so that nothing could happen without leaving a record.

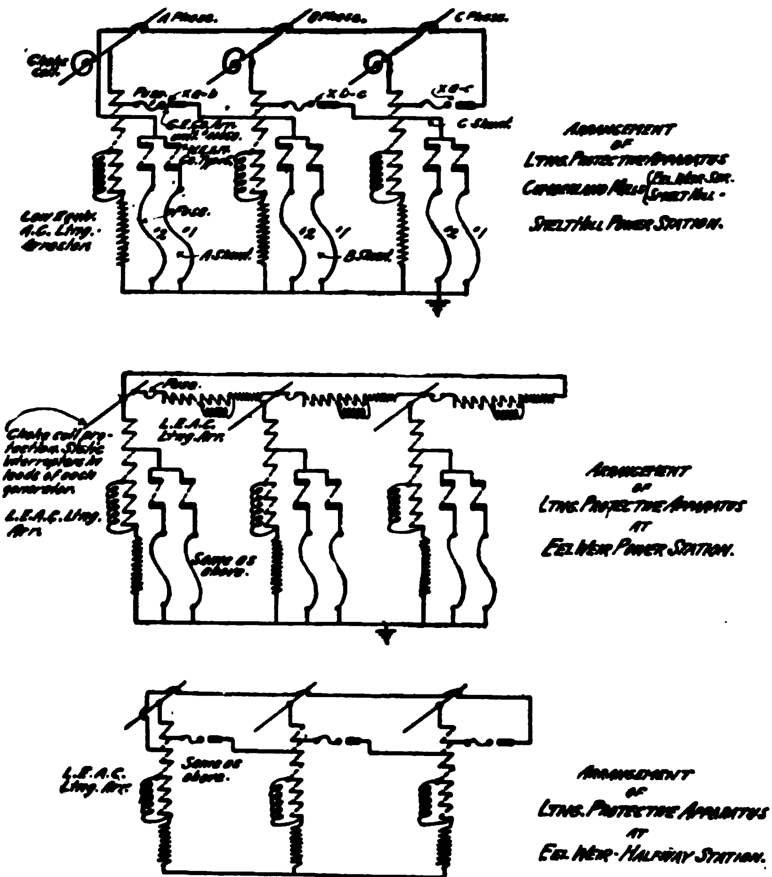


FIG. 2

The results to date are as follows:

Improved service during lightning storms.

When the arresters operated to ground there would often be a complete action over the low-equivalent arrester between line and ground as well as over the gaps and fuses in shunt thereto.

In any given discharge not all the fuse paths to ground would operate. Fuse paths in operation would sometimes blister the paper badly, again a paper would show burning.

Fuses did not always blow even though a discharge had passed

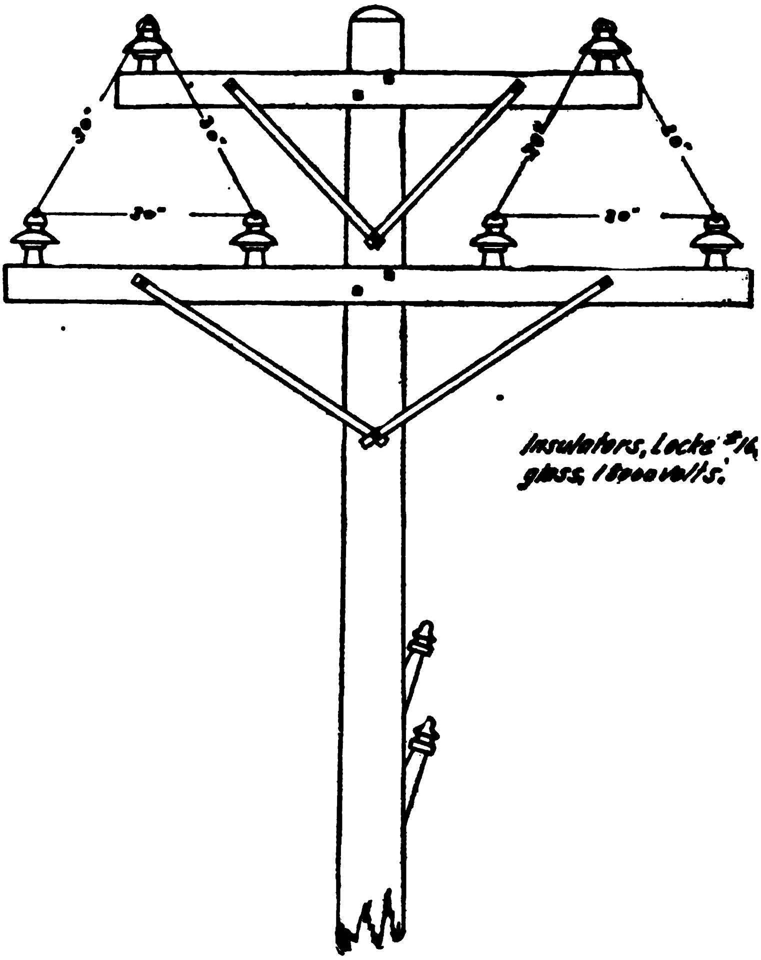


Fig. 3.—Detail of Eel Weir line construction Presumpscot Electric Co.

over them. The action over the fuse paths was apparently freer than over the arrester; that is, tell-tale papers on the fuse path showed larger holes and greater blistering.

The shunted-gap papers seldom show any current, from which, together with data from other sources, I conclude that the dynamic *current* seldom passes over the shunted gaps. It is the static or disturbing voltage only.

A new type of selective resistance arrester was installed last season, but too late to give much information. It has operated on several occasions, but there are as yet insufficient data to permit full comment on its performance.

FIG. 4.—Presumpscot Electric Co. View of Eel Weir half-way line lightning arrester house

Line-to-line. The results in this item at the Presumpscot Electric Company have been most interesting. They are:

A firmly established record of the existence of line-to-line disturbances in addition to those disturbances usually considered in lightning arrester operation. These disturbances were found to be taking place during " uneventful " periods of operation, with nothing to show from the general indications why they had happened.

Evidence, also positive, that line-to-line phenomena ap-

Fig. 5.—Presumpscot Electric Co. Interior of Eel Weir half-way line lightning arrester house

parently act like static line disturbance, both " slowly " and " suddenly ". This was evidenced by getting punctures in the shunt-gap papers of the low-equivalent alternating-current arrester line-to-line equipment at Eel Weir Power Station. In another case the resistances of the low-equivalent arresters used for line-to-line protection were fused. To do this, means a potential that could hold long enough over the series gaps and shunt and series resistances in series to fuse the wire. This was, however, a rare occurrence.

Indications existed that line accidents, such as the wind blowing the wires together, will cause a wave of phase-to-phase disturbance to travel a long distance and operate the line-to-

FIG. 6.—Presumpscot Electric Co. Eel Weir Falls power station

Just above basement windows, over the tail-race, special ground connections of broad copper straps may be seen. These lead off in two separate directions to additional grounds in order to assure good operation of the protective apparatus. The original ground is in the tail-race.

line protection; that on the closely adjusted gap sets the fuses invariably blew; and that some line-to-line action nearly always accompanied line-to-ground operation.

A tabulation added hereto shows the relative number of times, etc., this apparatus operated. From this I feel safe in drawing two conclusions: first, that proper line-to-line protection is as essential as line-to-ground protection. Thus confirming Wirt's contention.* Secondly, that the line-to-line operation is likely to take relatively considerable time, and, therefore, that in the long run high and stable resistance in the discharge

* A.I.E.E PROCEEDINGS, Vol. XXIII, p. 558.

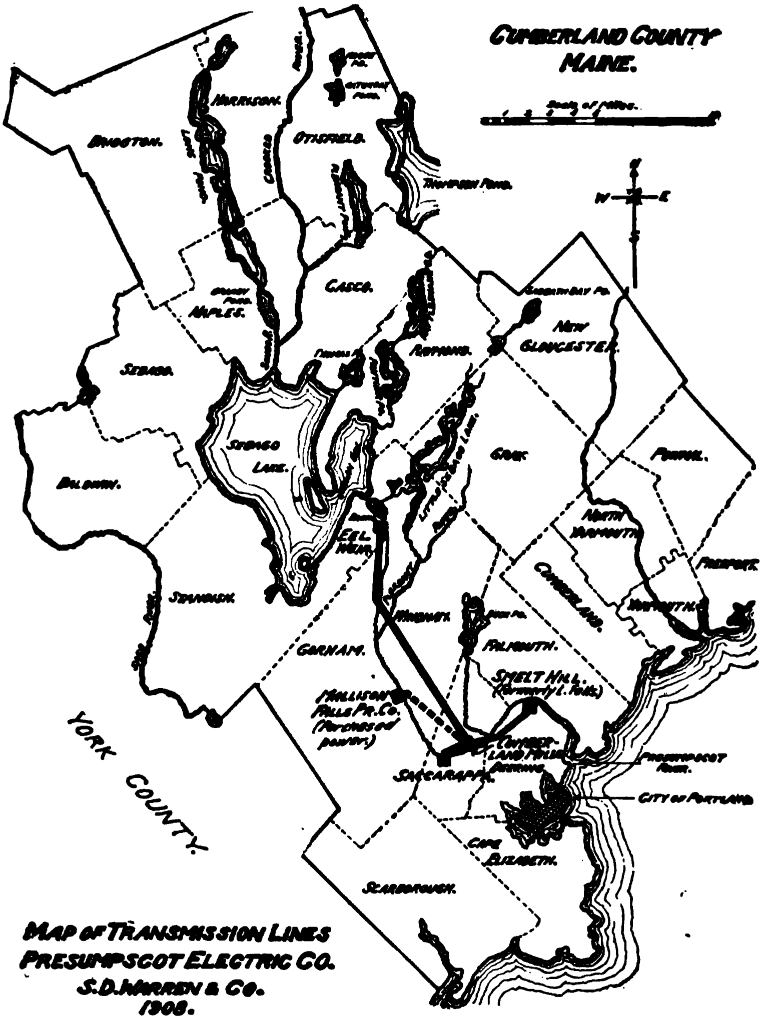


FIG. 7

Presumpscot River is one of the most interesting as well as one of the best water-power streams of its size in the United States. It is the outlet of Sebago Lake, which lies about 17 miles northwest of Portland. The lake is fed by Crooked River, a stream heading 35 miles farther north and within 3 miles of the Androscoggin. The area of the lake is 46 square miles; the total water surface on the drainage basin is 97 square miles; the area of the drainage basin at the outlet of the lake is 420 square miles, and at the mouth of the river 600 square miles. According to the survey made by Joseph A. Warren, of Cumberland Mills, the fall from the crest of the stone dam at the foot of Sebago Lake to mean low tide at the foot of the lower falls is 265.16 feet in a distance of 21.65 miles, or an average of 12.25 feet per mile.—*From U. S. G. S. Water Supply Paper. No.* 201, *p.* 72.

path is necessary for uninterrupted operation. A shunted-gap equipment, however, may be valuable.

Since line-to-line protection can be easily added to any multigap arresters not already so provided for, its adoption is not difficult.

I have assumed that it is as necessary for high-voltage installations as for low-voltage, for although I have as yet no data on this feature I believe it will be found there also. For this reason I would favor electrolytic arresters arranged in star with a common jar or jars to ground, since this does not impair the line-to-ground protection, and adds to the line-to-line.

Records of Operation

I wish to call attention specifically to the fact that all the evidence on which these remarks are based is not speculative but *actual*; that is, assured by tell-tale papers placed in the discharge paths at all parts of the respective systems.

It is safe to assert that in the case of Taylor's Falls, it has furnished us with data of great value to electrical engineering. In the case of the Presumpscot Electric Company it has enabled us to study very closely the operation of the system, to eliminate uncertainties, and to adjust conditions accordingly.

In both cases it has called for the employment of a large number of tell-tale papers, and an irksome filing of the same, but in my judgment the results have more than repaid us for the labor. In this connection, I recall that probably the first investigation of this character was made by A. J. Wurts to determine the necessary line protection in street railway service.

The U. S. Weather Bureau has it in its power through its local stations to help immensely in determining the local characteristics of lightning. These are of great importance to the problem as a whole.

Summary

As a result of the studies in lightning phenomena on Taylor's Falls and Presumpscot Electric Company's circuits, herein discussed, I would add the following summary on this subject.

Line disturbance by lightning.

1. Lightning disturbances on a line are more than likely to be local varying approximately from 1000 ft. or less, to several miles. The longer areas being less frequent.

2. They are likely to happen at any part of the line.

3. A direct stroke of lightning is not necessarily harmful: it depends upon the quality of the stroke, etc.

4. A line may be affected by a bound charge and direct stroke simultaneously. There is as yet no evidence to enable these to be measured separately.

5. Any grounded wire suspended on the line will tend to absorb a charge.

6. An overhead grounded system of one wire, two wires, or more, *above* the line wires is desirable.

7. An overhead grounded wire should be grounded at every pole near stations and important places, otherwise at every several poles.

8. When an overhead grounded wire is used exclusively for station protection, it should not be less than two miles in length and be grounded at every pole.

9. The higher the voltage design of the line the greater the possible disturbance from lightning to the line. High-voltage lines, therefore, need, more than low voltage ones, overhead grounded wire or its equivalent.

10. Lightning-rods added to the overhead grounded system probably add to the protective power. The full value of this is not yet determined.

11. Shattered insulators are liable to occur in every severe thunderstorm, but not in light ones. Puncture is more probable with power on the line at the time.

12. Insulators should be carefully selected for the service, to test under driving rain not less than two times normal voltage between line and pin with pin grounded. The equivalent spark-gap should be higher than any arrester path to ground on the line.

13. Horn lightning-arresters should be employed for extraordinary service only. The general arrangement known as the multigap selective path type promises to be of value.

14. Lightning-arrester stations to discharge line disturbances become increasingly expensive, and of questionable assistance the higher the voltage transmitted. Their total number depends on the length of line.

15. Wood poles may be effectively protected against splintering from lightning discharge by providing them with a small metallic conductor to ground.

Station protection.

17. Electrolytic lightning-arresters have so far behaved creditably, particularly in sensitive relief of grounds, but do not indicate a complete superiority over other types.

18. Line-to-line protection is desirable.

19. Apparently there cannot be too much protection on a plant. Every lightning-arrester added plays a part, but *practically* there is a limit. For many reasons it is obviously desirable to keep the station protection as simple as possible. It is, as yet, impossible to define what this should be.

20. If a full measure of line protection is added, such as overhead grounded wires, the stations will, in turn, be much relieved.

General.

21. Further and fuller data are required on the following:

a. Amount of direct stroke actually encountered on transmission lines.

b. Magnitude of bound charge possible on any given line—graded according to design—voltage.

c. Effect of line impedance to travel of static disturbance.

d. Corroborative data of the effectiveness of overhead grounded wires.

e. The relative value of overhead grounded wire for wood pole lines of short spans as against steel-tower lines of long spans.

f. Best relative position between overhead grounded wire and line wires.

g. Relative value of one, two, or three, etc., grounded wires.

h. Best relative position for lightning-rods.

i. Action of insulators under direct stroke.

k. Equivalent spark gap of high-tension insulators.

l. Relations between shunt resistance and given opening of horn gap.

m. Nature of line-to-line disturbances on very high voltage systems.

n. Equivalent spark gap of line choke-coils and consequent protective power.

Appendix

Lightning Performance Data, Season 1907. Presumpscot Electric Company, Westbrook, Maine

Summary.

Length of record, approximately, 26 weeks, June to December, 1907.
Number of changes to tell-tale papers 30 complete.
4 part changes (local).

Attending circumstances	Lightning	Clear*	Switching	Grounds and short circuits	Total
Number times disturbance occurred to lightning protective apparatus........	10	9	2	4	25

* Includes all other weather but lightning; causes not known, usually light discharges over some isolated unit; for example, phase to phase.

Distribution of Operation.

Two-phase. 2300 volts. Lightning protective apparatus.

Date	Line to ground %		Phase to phase %	
	Total = 18 paths		Total = 9 paths	
6/23-26		22.2		22.2
	Total = 22 paths		Total = 11 paths	
6/26-27		72.6		45.4
7/21-27		9.08		11.1
7/27-8/3		4.54		11.1
Average—per wk. for 26 weeks		4.18		3.45
" per disturbance....	(4)	27.11	(4)	22.45

NOTE: Figures given equal percentage of total protective apparatus paths operating.

Three-phase. 11,000 volts. Lightning protective apparatus.

Date	Line to ground %		Line to line %	
	Total (paths) = 33		Total = 15	
6/18-19	"	9.1		46.6
6/23-26	" = 39	48.8		87.
6/26-27	" = 33	54.8		73.2
7/7 - 8	" = 39	33.3		46.7
7/8 - 9		59.1		33.3
7/14-21		7.7		20.0
7/21-28	" = 42	40.4	" = 18	77.8
7/28-8/4		71.5		94.6
8/25-9/1				11.1
9/1 -15				11.1
9/15 22		14.3		33.3
9/22-29		50.0		78.0
9/30-10/6		2.38	" = 15	40.0
10/6 -13			" = 18	11.1
10/20-27				16.7
10/27-11/3		4.76		11.1
11/3 -10		9.52		50.0
12/1 - 8				5.55
12/8 -15	Special by switching	35.8	" = 12	75.0
Average per wk. for 26 wks.		17.0		31.7
Average per disturbance	(14)	31.5	(19)	43.3

NOTE: Figures given equal percentage of total protective apparatus discharge paths operating.

Prominent characteristics brought out.

1. Line-to-line disturbances pronounced, and of greater frequency than line-to-ground disturbances.

2. Line-to-ground, freer over fuses in shunt to low-equivalent, but this does not prevent the low equivalent operating at the same time.

3. Circuit-breakers set too light, objectionable; open on blowing of fuses, disturbing the balance of the system, and then frequently causing a loss of power while stations are getting into synchronism again.

Operation of power plants.

The Presumpscot Electric Company is not always able to operate to the best advantage electrically, because of the conditions which obtain. In the first place, the flow of water must be maintained primarily for the interest of the direct development of the mill at Cumberland Mills. Again, all the hydroelectric stations are on the same river, and while the flow of this is controlled, the company must, of course, protect the other users on the river. This introduces another variable. Furthermore, the supply of water to Saccarappa and Smelt Hill stations is affected by the run-off from the territory between the lake and the sea on which the streams are not ponded. It becomes evident, then, that during heavy rains, or in the spring, when there is a large amount of side-stream water, the flow from the lake may be well cut back, and Eel Weir is then unable to furnish its full supply. On the other hand, if the electric station below calls for water, more water must be run through the Eel Weir station than is desirable. In order to furnish a uniform flow at Cumberland Mills, it is sometimes necessary to store in the Saccarappa pond, and again to sluice, thus producing a variable head.

There are a number of other conditions which have a greater or less effect upon the system, and it is to harmonize all these that the company maintains turbo-generators, always having one floating on the line prepared to make good any little deficiencies, and the other two are usually warmed up ready to run, so that whatever the demands of the paper mill, they can be met up to the limit of the water power at that moment available, plus the turbine. If the load exceeds that, steam engines must then be substituted for motors on some of the large groups in the mill.

Discussion on "Comparative Tests of Lightning Protection Devices on the Taylor's Falls Transmission System", and "Studies in Lightning Performance, Season 1907." New York, May 19, 1908

H. W. Buck: The valuable data presented to-night include the most comprehensive and systematic record of lightning disturbances which has been presented to this Institute. In the old days of electrical transmission most of the trouble we had to cope with was due to the station apparatus itself, as the insulation of the lines was relatively high. As line voltages have risen with the progress of the art, the insulation of station apparatus has risen in proportion. Presumably lightning stresses have remained constant, so that at the present time we have insulation in our stations which perhaps on the high-voltage transmissions is high enough to withstand the original lightning surges, and the troubles seem to be shifting out upon the line itself. I think that this is the most noticeable feature of this paper. During the storms spoken of in the paper, many insulators were shattered, poles were shattered, and some cross-arms burned, and so on, and yet only one transformer bushing was damaged within the station.

It has conclusively been shown that these line troubles have been reduced by means of the overhead ground-wire. It is shown not only in this particular system, upon which we have the record to-night, but the experience over all this country with transmission lines, where the overhead ground-wire has been installed, shows similar corroborative evidence. There are perhaps three functions of this overhead ground-wire: it takes the direct stroke and it allows the induced charge to accumulate on the ground-wire instead of accumulating upon the transmission wire itself, so that when the cloud which induced this charge discharges itself through a lightning flash the corresponding charge of opposite polarity on the ground-wire can discharge itself through the ground connections on the pole, instead of having to spill over the insulators. Another important function of this overhead ground-wire consists in shielding the transmission wires from induced potentials between phases, due to neighboring lightning discharges, which are presumably of high frequency. The guard-wire forms one side of the circuit and the ground the other, so that we really have a short-circuited shield against induction on the transmission wires—the ground and the shield-wire being connected by electrical connections. If this theory be correct, it would seem to be a decided advantage to have two overhead ground-wires rather than one, a connection being made between these two shield-wires at every pole. Then we should have a shielding effect in the vertical plane and also in the horizontal plane against induced potentials, between the phases in the transmission wires. These short-circuited loops in fairly close proximity to the transmission wires might represent some induced loss on the normal frequency of the transmission system, but I doubt if it would be enough to be very serious; whereas at the frequency of the lightning discharge the possible induced current might be high and give a decided shielding effect to the transmission wires.

The evidence of the spilling over of accumulated charge in the insulators seems to show that the actual magnitude of the momentary current in this ground-wire is very large. I think it would be interesting if some form of current-recording device could be installed experimentally in some of these guard-wires, in order to give an indication of the magnitude of the currents. It would seem that along transmission lines there might be installed in circuit with the guard-wire a crude form of ballistic galvanometer, which would give a record of the maximum current flowing in the guard-wire during a storm. It would tend to indicate what conductivity ought to be established in these shield-wires to take care of discharges, and would give valuable records.

It is quite noticeable from the records of this paper that lightning storms follow certain well-defined paths throughout a region. There seem to be certain sections of the line which have borne the brunt of the lightning discharges; whereas other sections of the line have been practically free from trouble. I think that this accords with the experience of the Weather Bureau, in showing that lightning storms tend to progress along certain well-defined topographical paths. The frequent shattering of insulators as shown in these records indicates the desirability of developing some form of insulator which can withstand such a stress. The problem is a mechanical one, to get some material that can withstand the sudden application of the heat of an arc without it resulting in the insulator being shattered. It is not so bad to have a momentary short-circuit on a system, provided it blows itself out and leaves the insulator in comparatively good condition, but if every time a spill-over takes place the insulator is going to be destroyed, the operative difficulty becomes a serious one.

The horn arrester seems to have assumed a very important function in coping with the lightning problem. It is cheap and easy to insulate, and it can be put out of doors and withstand heavy rains without the insulation being impaired. It can also withstand very violent fireworks without the destruction of any valuable apparatus. In conjunction with the development of the horn arrester the problem of a good form of resistance is brought up. It seems to me that no really satisfactory form of resistance has yet been developed. The water rheostat is satisfactory under some conditions, but it is bulky, and in cold weather there is trouble from freezing. A resistance ought to be developed which can withstand frequent discharges and which can carry without destruction, for periods of several consecutive seconds, a large dynamic current from the generators. With a resistance of this kind, sufficient surge current could flow to ground without necessarily shutting down the system.

It is interesting to note in this paper that certain discharges have been noticed on the secondaries of the transformers. This accords with my experience and with that of other engineers with whom I have talked. I have known of several instances where overhead lines pass through transformers into underground cable systems, where cable punctures have resulted simultaneously with thunder storms along the overhead lines. This indicates a possible necessity for having lightning-arresters of some form on the secondaries as well as on the primaries of the transformers. I have noticed in the Taylor's Falls installation that there are such static dischargers on the secondary circuits.

It is also interesting to note that the tell-tale papers in shunt with the test choke-coils on the line have been punctured. This certainly indicates that choke-coils act as barriers to the progress of these lightning surges in spite of the fact that this has been disputed so many times. It is evident that choke-coils are a decided protection where they are installed.

In general, I believe that with steel construction adopted throughout a transmission line so as to eliminate the burning and shattering experienced in wooden construction, and with one or more guard-wires installed along the line and over the transmission wires, that most of the serious lightning troubles on overhead lines will be eliminated.

P. M. Lincoln: In Figs. 11 and 12, Mr. Vaughan shows a number of curves the ordinates of which purport to give the static stress upon the insulators. I am not convinced that they do represent stress on those insulators. The ordinates of these curves are taken as the diameters of holes which were punctured in the tell-tale papers, and from that diameter is deduced the stress upon the insulators. I doubt if the diameter of a puncture in the tell-tale paper is an indication of stress on the insulator; I think it an indication of the current that has passed through that tell-tale paper. The current may have come from a lightning stroke, but more likely it has come from the passage of the dynamic current.

J. F. Vaughan: The question of interpretation and graphic representation of these tell-tale papers is open to discussion. It has been given a good deal of thought in the preparation of the curves. The curves are drawn up to show graphically or pictorially the differences in stress on the insulators, spill-overs of static and dynamic discharges; and the scale assumed in plotting the curves is intentionally exaggerated in the lower ranges to facilitate comparison of the smaller punctures. The curves should be interpreted in the liberal spirit in which they were plotted; that is, as a general indication (as accurate as possible) of the relative activity of disturbances in each case.

P. H. Thomas: These papers differ from most lightning-arrester papers in that they are a simple record of practical operating results and not a compilation of theories. What is most needed in the study of the lightning problem is not so much theory and speculation as sufficient data and knowledge as to exactly how lightning affects a transmission line, so that an intelligent design can be made of protective apparatus, and so that the action of such apparatus can be properly judged. These papers go a long way toward showing the nature of the attack of lightning on the high-tension transmission line. Of course the data here recorded are not necessarily typical of all lines, but they indicate in a general way what may be expected to happen.

The interpretation of these punctures in the tell-tale papers is important. It will be found on examining the data that one storm occurred when no generator potential was on the line at all; in another case the potential went off in the early part of the storm. In these storms, then, at least during the major part of them, there was no actual generator potential on the line. The punctures in the tell-tale papers were just as severe during the times when there was no generator connected with the line as at any other time. Most of the punctures show, on examination, that the fibres of the paper are unburned even when large holes appear, showing them to be purely static discharges. In other words, the holes in the punctured papers are simple records of the static passing over the line.

I have not counted the total number of so-called spill-overs, but there must be hundreds of them. These are cases where a static discharge has passed over the wire to the pin from the surface of the insulators and not a capacity current to the pin. Only a small percentage of these spill-overs have injured insulators.

It is interesting to know that there has been very little disturbance of any serious character at the stations. Mr. Buck draws the conclusion that it is because the insulation of the station apparatus has been raised in relation to that of the line. It seems to me that the reason for the relative immunity of the stations is that the action is entirely local, the attack of the discharge being so sudden that it cannot pass more than a very short distance along the line. It is not of sufficient energy to cause any very great disturbance unless it should start an arc from the generator. It has been frequently assumed that the high potential on the line wire, due to lightning, is the release of a charge. This may be true, but I think the evidence points the other way. This is a matter which ought to be studied. The evidence suggests more strongly, it seems to me, the direct jumping to the line wire of electrical energy direct from the atmosphere and not the drawing of the charge from the ground.

V. E. Goodwin: The papers presented this evening are of special interest to me as I lived several years in Minneapolis and am quite familiar with the nature and severity of the lightning storms in that vicinity. I also inspected the Taylor's Falls system with Messrs. Vaughan and Neall during the preliminary testing of the line and protective devices. I was then of the opinion that it would be difficult to draw definite conclusions from the results they would obtain, as the system was so completely equipped that it would be impossible to differentiate the protective values of the various devices. I now believe that the papers presented to-night show conclusively that reliable data have at last been obtained on the effects of lightning on a transmission system and on the relative values of various types of overhead ground-wires.

The phenomenon regarding direct strokes of lightning on transmission lines mentioned by Mr. Vaughan has been reported on several other systems. One would naturally think that a line would be more subject to direct strokes after the wires are up than before. It seems probable that where the wires are up the charge dissipates over several insulators and poles and therefore does not splinter or burn the poles. I therefore question the ability of an investigator to determine from tell-tale papers whether a disturbance results from a direct or induced stroke of lightning.

The magnitude and intensity of many of the strokes indicated in these records give us a good idea as to what is required of a station lightning-arrester. The records indicate that the station arrester did not have sufficient discharge rate to relieve the line at those points, thus causing the horn arrester, which had a higher breakdown point, to discharge. In designing the latest types of arresters great care has been taken to avoid all series resistance and to increase the discharge rates. This feature has been thoroughly carried out in the aluminum type electrolytic arrester, by the use of large plate area and an electrolyte of very low specific resistance, thus giving low internal resistance and a maximum discharge ability.

It is interesting to note that many of the induced strokes on the Taylor's Falls line were highly concentrated and often of great intensity and volume. This is indicated by the storm of July 4, where one puncture 1.75 in. in diameter was recorded. The absolute protection of a line under such conditions becomes a very difficult problem. It is evident that one or two overhead ground-wires are of considerable assistance in shielding the line wires, but at best they can only be of partial protective value. The problem of a line-type lightning-arrester for this purpose involves the installation of several arresters per mile, and this, of course, is prohibitive in any transmission line of over 2300 volts. The only case where such arresters can economically be installed is at an exposed point, where experience indicates that the expense is warranted.

The Taylor's Falls tests indicate that during every storm a great many insulators spilled over without any resultant damage to the insulators or interruption to the service. I believe that the only means of entirely protecting an overhead power circuit lies in the development of an insulator which will not puncture, and, while having a fairly low spill-over, will not shatter. This perfection in the petticoat type of insulator is probably out of the question, but I believe it can be attained by a properly designed and proportioned insulator of the suspension or strain type. Such an insulator would be the equivalent of a line arrester at each pole or tower on the line.

E. E. F. Creighton: The two additional subjects I wish to discuss are the interpretation of tell-tale papers and the use of resistance type of horn arresters. The conditions which muddle the tell-tale records are: first, the impression of several static discharges on each paper before they are removed; secondly, the complete destruction of the static puncture holes by dynamic current. A fraction of an ampere of dynamic current for a half cycle of the generator wave is sufficient to destroy the static record. The authors were fortunate in obtaining records on an idle line. It may be suggested to those who are willing to aid in collecting data on this subject that the only data of great value in the study of lightning potential should be taken on an idle line, and furthermore should be collected on moving tapes by clockwork so as to separate the punctures due to each cloud discharge.

The value of the resistance type of horn arrester for discharging lightning increases as the value of series resistance decreases. On the other hand, the disturbance that one of these arresters may cause on the line increases as the series resistance is diminished. The menace resulting from a discharge through one of these arresters to ground may be either one of two effects, or both. First, the arrester may take sufficient current to overload the circuit-breaker. Opening switches under overload conditions should be avoided as much as possible, to say nothing of the interruption of service. Secondly, if the resistance is sufficient to prevent overloading, there may be a menace to the insulation by the operation of one phase only, especially on an insulated neutral system. It requires about one to two seconds at best for the arc to rise on the horns and go out. During this interval the arc varies from a short length to a very long length, and if there is a possibility of setting up a surge on the system this arc is most likely to produce the condition. On any particular system these arcs may occur repeatedly with impunity, whereas on another system the surge conditions will be such as to cause a destruction of apparatus on some other part of the system. To illustrate this two examples are cited:

On a 17,000-volt, 60-cycle, delta-connected system a single gap in series with enough resistance to limit the current to 0.5 ampere was connected between line and ground. Even with this high resistance all five of the arresters in the station on three feeders discharged continuously so long as the arc played across the gap to ground. A lightning-arrester of so limited a discharge would have little practical value, yet the surges caused by the discharge assumed dangerously high values.

As a second example, it is a common occurrence on cable systems to have several failures of cables after one has taken place, due probably to the surges set up during the first failure.

If one goes back over the history of the use of horn gaps with series resistance, he will find the hope always held out that an operator will finally obtain the right adjustment of resistance to give excellent protection without a resulting interruption of service. This has never been accomplished, and I think it can be shown that it never will be.

If we did not have the aluminum arrester it would be worth while working out the best conditions for the resistance horn-gap arrester. A comparison of the two will show the limitation of the resistance horn type and the uselessness of the development. At 60,000 volts every ampere of discharge through the series resistance of the horn gap represents, roughly, 60 kw. per phase, or 180 kw. If an arrester will not discharge 100 amperes, I think it will not take the usual run of heavy discharges. With this rated discharge the generator would be called upon to furnish 18,000 kw. On the other hand, if an aluminum arrester is used, the energy taken from the generator will be less than 20 kw. and the rate of discharge of lightning will be several hundred amperes at the same abnormal value of potential. The valve action of the aluminum arrester prevents almost entirely the flow of dynamic current at normal potentials and has a free discharge only at abnormal potentials. This information is sufficient to show the futility of using the resistance type of horn-gap arrester.

Furthermore, the current taken by the aluminum arrester from one phase to ground is leading, the same as the capacity current of the line or cable, and consequently one phase may arc continuously between line and ground without setting up high surges on the system. It should be noted that the aluminum arrester actually maintains the voltage and thus prevents grounding the line conductor.

President Stott: In listening to the discussion, I recall the experience of eleven years ago with the Niagara transmission lines. I am not certain whether this was the first line equipped with overhead ground-wire, but at all events it was so equipped when it started. After a few months' experience with the overhead ground-wires it was decided to take them down, as in the choice of two evils the lesser one seemed then to be the troubles due to lightning. This was due to poor material in the ground-wires themselves, as they were continually breaking and short-circuiting the lines. Now eleven years after, we hear that as the result of a most elaborate series of tests and investigations. the ground-wire gives the most certain protection. In a practical way there is every reason why it should. No one ever heard anywhere of an underground cable being struck by lightning. That means that if the ground itself is above the conductor the line is safe. We cannot possibly afford to put all transmission lines underground. A 60,000-volt underground transmission line 200 miles long is absolutely impossible from a financial or commercial standpoint; but instead of putting the wires underground, we can in effect put the ground above the wires. The most perfect protection will be got where we have the most perfect network of ground-wires above our conductors. I think everything said to-night points to that fact.

Now to avoid ordinary troubles there must be a high factor of safety in all apparatus. Troubles with underground cables are almost unknown outside of mechanical damage and faulty joints, and the reason is that those cables are made with an extremely high factor of safety; for instantaneous voltage it is five; for continuous service, two. Just as it is with a human being, if a man is in a weakened condition every few germs that come along will give him a new disease; but if he is strong enough they won't affect him at all. We have got to make our system germ-proof, as it were, and have a very large factor of safety on the insulators. That, and the ground-wire, I think, is going to be the solution of our overhead transmission work.

J. F. Vaughan: I am sorry not to hear more discussion on the interpretation of tell-tale papers, as there is plenty of material for discussion. It is rather surprising that with the necessarily crude methods of measurement used there are not more apparent inconsistencies in the results. For instance, the three wires grounding the three pole pins through individual tell-tale spark-gaps are not more than a few inches apart and are mounted on porcelain knobs only, which might be expected to allow disturbances of such intensity as have been indicated by the papers to break across from wire to wire. This fact brings out one point which has not been touched on, and that is the lack of pronounced phase-to-phase disturbance, indicating that the main stresses which are between wires and ground do not greatly differ in the three wires.

N. J. Neall: I wish to emphasize again the points which I have made about insulators. According to the theory which I have advanced in my paper, suspended-type insulators would be subjected by lightning to greater disturbance locally than any insulator so far used for lower voltages, because I am assuming that there is no special overhead protection at all, and am taking the broad case. If the transmission wire takes this lightning charge, the charge must get to the ground some way or other, and the only place at which it could do so would be presumably by way of the insulator support. The suspended type insulator has not come into the Taylor's Falls problem, and we have no data respecting it; but if insulators could be studied with reference to the equivalent spark-gap we would probably find certain explanations of the phenomenon at which we can now only guess. I think that is a point on which the Institute should have the fullest possible information, if not from a practical reason, certainly in connection with the advancement of the art, and, perhaps, indirectly, of the science.

V. D. Moody (by letter): In a paper presented at a recent meeting of the Institute,* Messrs. Rushmore and Dubois recommended for insulator protection steel rods with ends pointed, bolted to the vertical members of the towers and projecting above the highest point of the line. This method of protection was freely criticized, but my experience is that this type of arrester is highly valuable.

Several years ago this type of arrester was used on the Winnipeg hydroelectric installation at Winnipeg, Canada. The transmission line was 65 miles long, delivering about 20,000 h.p. at 60,000 volts, 60 cycles. From the power house to the substation duplicate transmission lines of No. 00 B. & S. hard-drawn cable, with a hemp centre, were run in duplicate on steel towers. This line crosses the Winnipeg River with a span of about 760 ft., on towers 72 ft. high, each weighing about 6 tons, with a sag in the line of about 23 ft. at 50 degrees. The standard towers are 40 ft. high, weighing about 2400 lb., spaced 500 ft. apart with a sag of about 14 ft. at 50 degrees. There are four railroad crossings. At Winnipeg, this line crosses the Red River with a 1100-ft. span, the towers are 105 ft. high with a line sag of 45 ft. at 50 degrees. These towers weigh 15 tons. The railway and river crossing towers are on concrete footings, and are grounded with a ground-plate. This transmission line has 10 complete transposition spirals and is paralleled by a telephone line of No. 8 B. & S. hard-drawn copper wire on porcelain insulators on the towers. The telephone line was transposed at each tower. The telephone line and transmission line insulators were made of the same kind of porcelain.

On all of these towers this steel-rod type of horn arrester was used. In operation it was found that the protection afforded was extremely valuable, as none of the high-tension insulators was punctured in several very severe lightning storms. In this country the storms are very severe in the summer months. In one instance five miles of telephone line was knocked down and insulators broken without breaking any of the line insulators, although the effects of the storm were felt in the sub-station by throwing out of synchronism, momentarily, the 800 kw. motor-generator sets.

This line has now been in operation since June 1906, and has never had a shutdown. As the storms have been severe, I feel assured that these arresters are doing good work, as this is the only protection on this line.

It appears to me, that this type of arrester with a ground-wire and multigap station arresters with choke-coils will afford protection that can be relied upon.

* TRANSACTIONS A. I. E. E., Vol. XXVI, page 425.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

THE EVOLUTION OF ENGINEERING

President's Address

BY HENRY GORDON STOTT

Eighty years ago Thomas Tredgold defined engineering as " The art of directing the great sources of power in nature for the use and convenience of man." Progress in engineering has been greater in the eighty years which have elapsed since this definition was made than in the previous period of 4500 years beginning with the first great, tangible piece of engineering, the pyramid Cheops.

The question naturally arises: does this definition hold good to-day? Is it broad enough? If not, how can we better define the engineer's sphere of activity? If we accept Tredgold's definition as our standard, will we reach the position in society which belongs to us by right of education, achievement, and highly developed power of logical deduction from facts observed and investigated?

Engineers may be divided into two gene al classes: first, those who believe that the engineer should be restricted to a specific vocation, such as elcctrical, steam, hydraulic, pneumatic, or sanitary engineering, etc; second, those who wish to see him take his place not only as an engineer but also as a public-spirited citizen and leader.

The great amount of specialization which obtains in electrical engineering to-day is instanced in the subdivisions now found, such as telegraphy, submarine telegraphy, telephony, wireless telegraphy, railway signaling, underground cable engineering, high-tension transmission, electric lighting, electric railways, alternating-current generator designing, direct-current generator designing, railway motor designing, converter designing, transformer designing, railway, lighting, telegraph, and telephone switchboard engineering, etc.

The score or more of divisions of electrical engineering which exist to-day are the necessary outcome of the consolidations of manufacturing and other interests into a few large concerns: they are the natural economic results of competition. As these consolidations have undoubtedly resulted in greater efficiency and, therefore, in reduced cost of production, there is every reason to expect a continuance of this evolution from the simple factory manufacturing only one article, to the complex one which manufactures many things. In such a factory it is manifest that as soon as any one article is called for in sufficient quantities to require the entire time of the man in charge, a new department will be formed and another subdivision of engineering created. In exactly the same way we will find consulting engineers who specialize on cables only, others on illumination, etc., and on any pursuit which is of sufficient importance to claim undivided attention. This process of segregation is evidently one of infinite application in all pursuits, tending strongly to an ever narrower development of the individual, but at the same time increasing his efficiency to a maximum in his own particular specialty. This increase in efficiency, however, will cease if the engineer becomes so highly specialized as to ignore the necessity of keeping in touch with the entire sphere covered by his company, as the evolution of each branch must be synchronized with that of all.

The other class, to which the term " second " has been arbitrarily assigned merely to indicate its numerical inferiority, embraces all those who have broadened their field through self-education, experience, opportunity, and natural adaptability for administrative work. The term self-education is used advisedly, as both classes are assumed to start with the same technical training, and as a matter of actual fact the second class almost invariably evolves from the specialists.

The engineer who is called upon to report on a projected railroad, for example, must also be a student of political economy in order to give proper weight to the various economic problems which must be first studied before he reports upon the advisability of even making a survey. He should be thoroughly familiar with the general organization of the state governments through whose territory the road may run, as well as have a general knowledge of their laws affecting corporations, franchises, etc. In order efficiently to carry out his work, it will be necessary for him to come in contact with various officers of the state and city governments, so that he should be a man of general and broad culture, capable of meeting anyone with credit to himself and the company he represents. Lastly, if he is personally acquainted with some of the more important state or city officials, or the members of the legislatu e, his work may be greatly facilitated and his services be just so much more valuable to his employer.

Tredgold's definition of engineering evidently did not contemplate this enlargement of the engineer's sphere, and it is only by a natural process of evolution that some have reached this stage.

The second class is necessarily a restricted one, as, whilst the legitimate field of work of the engineer is extremely broad and almost unlimited, yet as a rule he has apparently decided to keep in the background and only come to the front when called. The result of this policy is that when the opportunity comes, the engineer is taken at his own valuation and passed over for others who, whilst not suffering from modesty, are lacking in engineering education and experience, and therefore are forced to call in engineers (to act in a subordinate position) to supply the incumbent's deficiency in the qualifications necessary for the office.

A good illustration of this policy is furnished in the appointments made on two state public service commissions, in which the ten offices are filled by gentlemen whose occupations had been as follows; six lawyers, two manufacturers, one political office-holder, and one engineer. These commissioners have control of all matters pertaining to public service corporations; and as their functions are of an inquisitorial and critical character on subjects which are almost exclusively of an engineering nature, it is quite evident that their lack of engineering knowledge must be a severe handicap, not only to them but much more so to the state that employs them, and lastly, but not least, to the company or corporation suffering from their well-meant but misdirected efforts.

What is the cause of this anomalous situation. Is it entirely the fault of the executive who makes these appointments? Has not the whole body of engineers some share in the blame? We have seen that there is to-day an inherent tendency to specialization in engineering, and that by far the greater number of our members are becoming experts in one or two subjects only, and that comparatively few attempt to keep in touch with the more general aspects of engineering. This condition is caused not so much by a lack of willingness as by lack of time and opportunity.

This centrifugal force acting on our profession has fortunately a nearly equal centripetal one which is found in such societies as the American Institute of Electrical Engineers, by which all can once more be brought back to a common centre on the common ground so clearly described in our Constitution, which says that the object of the American Institute of Electrical Engineers "shall be the advancement of the theory and practice of Electrical Engineering and of the Allied Arts and Sciences."

The conference held in Washington, D. C., last month, which was called by President Roosevelt to consider what steps should be taken to conserve our natural resources, was preceded by a series of conferences held by the presidents of the four national engineering societies, at which a series of broad resolutions were drafted and afterwards presented at the conference as representing the opinions of 20,000 American Engineers.* The Committee on Resolutions presented a very able report to the conference, embodying practically everything we had recommended, with one exception, as that particular item had already been covered in a bill introduced into Congress. The resolutions were unanimously adopted.

Several important deductions may be made from this incident. First, united recommendations after careful investigations of facts by engineers, on any public question involving engineering problems, will be not only courteously received but welcomed and highly appreciated by our state and federal governments. Secondly, the facts presented at this conference were of such a far-reaching and important nature that every member of this Institute should feel it is his duty carefully to study the able papers presented, and to further in every way possible the policy of preserving our natural resources. In this we all can unite, no matter whether we are specialists or general engineers. Thirdly, coöperation on the part of the four national engineering societies is absolutely essential to success in any movement of this kind; and, as a corollary, success is certain if we coöperate. Fourthly, if engineers are to take the place in society which belongs to them by right of education and training, they must

* PROCEEDINGS A. I. E. E., June 1908, Section I, p. 5.

take an active part in matters of general policy or civic interest, no matter how remote these matters may seem from Tredgold's definition of engineering.

After nine of the ten commissioners' names previously referred to we can find the significant words, bracketed," active in politics. " Is there no lesson for engineers here? Is it not their civic duty to the state and nation to take a more active part in public affairs, giving of their special knowledge freely, as may be required of them, at the same time insisting upon the same high ideals of faithful, honest, and loyal performance of duties in public life as they have been accustomed to in their every-day work as engineers?

These suggestions are clearly outside the scope of this Institute as set forth in its Constitution, and in all probability would be pronounced heretical in any of our engineering societies, so that to carry them out it may become necessary to organize a new society in which membership would be limited to members of the four national engineering societies, and whose object would frankly be to use all legitimate political methods to influence legislation on matters affecting engineering; for example, such as carrying out the recommendations of the Conference on Preservation of Natural Resources, or the application of the principles of political economy to the laws affecting public utility commissions, etc.

An enormous amount of work must be done in order to induce our state and national legislatures to pass the necessary legislation in regard to preservation of our natural resources. No body of men is so peculiarly qualified to advise on these matters as that composed of engineers. Such a society could with propriety take up the consideration of many problems of which the public now hears only one side, and that usually the demagogue's, simply because the engineer has maintained an attitude of reserve. His silence is frequently mistaken for either assent or guilty knowledge, when in nine cases out of ten he remains silent either from a mistaken policy, dictated possibly by his employer, or because he considers it undignified to reply to criticism.

Belonging to a society whose object it is to guide and instruct public opinion in engineering matters, this feeling would soon disappear, and the benefit of coöperation among engineers in this respect would make this society's influence felt in every city and state in the country. Our large corporations and manufacturers are realizing as never before the benefit of publicity departments, not only for advertising purposes, but for the purpose of disarming adverse criticism by a calm statement of facts.

In conclusion, let us remember that if we wish to progress and assume our proper place in the world, we must be aggressive and not passive in allegiance to our engineering societies; that the day is long past for hiding our light under a bushel, and that instead of Tredgold's definition of engineering, the following more correctly expresses the position of the engineer to-day:

Engineering—The art of organizing and directing men, and of controlling the forces and materials of nature for the benefit of the human race.

Discussion on "The Evolution of Engineering." Atlantic City, N. J., June 29, 1908

Charles F. Scott: In the president's address reference is made to the part that the presidents of the national engineering societies played at the conference at Washington. One of the speakers referred to that conference as marking an era in American thought and American action. It seems to me it also may mark an era in the position the national engineering societies are to take as to public matters in general.

As a society, and as engineers, we may well congratulate ourselves on the part our president took in formulating the resolutions which were the formal outcome of that great and notable conference. It has been the ideal of many of us that the engineers of America, through their engineering societies, might get together for concerted action such as this. That was one of the ideas underlying the project in the Engineers' Building, and it is a happy outcome that so soon after it was opened, the founder societies have taken such an important part in this great national work.

The president's address admirably indicates the position which engineers should take in the future with regard to matters of this sort. The other papers this morning have been along the same lines, calling for the highest action, the coöperation of engineers, on a larger scale and in larger matters, and we can also congratulate ourselves that the new president, in sounding his keynote, has looked also to the broader and more useful development of the engineering society.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

ELECTRICITY AS VIEWED BY THE INSURANCE ENGINEER; SHOULD THE A.I.E.E. INTEREST ITSELF IN FIRE PROTECTION?

BY C. M. GODDARD

If news had been received during the last six months of the total destruction of our fleet of battleships on its way to San Francisco, even without any loss of life, what a calamity it would have been considered, and how messages of sympathy would have poured in from all the governments in the world. The value of that fleet is probably less than $125,000,000; the property loss by the conflagration in the city of San Francisco, toward which that fleet was headed, of $350,000,000 by one fire, brought similar messages because it was an unusual occurrence.

The property loss by fire [in the U. S.] for the year 1907 was $180,000,000; the average annual loss for the last 32 years was $134,000,000; the national debt at its highest point was $2,845,000,000, or a little over two and three quarters billions; the insurance companies have paid $2,500,000,000 in losses since 1860; the total property loss by fire has been $4,250,000,000 since 1875.

There are approximately three hundred insurance companies doing business in this country, one thousand companies, or more than three times the present number, have failed or been retired since 1850. The three hundred companies have risks outstanding of over $30,000,000,000.

The annual number of fires in American cities averages 40 for each 10,000 of population as compared with 8 for each 10,000 population in European cities. The annual per capita loss in Austria, Denmark, France, Germany, Italy, and Switzerland varies from 12 cents in Italy to 49 cents in Germany, with an average of 33 cents as compared with $2.47 in the United States.

There is no question but that 50% of our fires are due to what we technically call " faults of management "; this includes all sorts of easily avoidable conditions that are likely to cause or aggravate fire hazard, a more common word would be " carelessness ".

Just after the Collinwood School tragedy, a prominent metropolitan newspaper printed the following editorial on this unnecessary loss of life:

> A spasm of horrified emotion has passed over the country as a consequence of the deaths of a crowd of children in the fire which destroyed the Collinwood School at Cleveland. The horror is natural. It is a credit to the country. But the fire and its results were the natural effects of a succession of causes which discredit the country because they are characteristic of the country. The horror and the sympathy are human; they are common to all civilized communities; the recklessness which caused the unspeakable disaster is American. It has no counterpart elsewhere.
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> The city authorities, the school authorities, all were negligent. Behind their negligence stands the great, gaping negligence of the public, the same negligence that causes annually in the United States more accidental deaths and injuries than three great wars.
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> There is terrific loss of life and limb in this country from preventable causes. No other land shows anything like it, or anything approaching it. This is not because of the vastness of our population, but because of its carelessness. We are the most careless people on earth. We permit a looseness of conditions, a recklessness of method, or a method of recklessness which would not be tolerated in Great Britain or Germany or France. This laxity runs on our railroads, pervades our coal mines, meanders in our mills, asserts itself in the slovenliness of our cities and our vacant lots and is traced directly to our homes along the icy sidewalks to our front doors and the doors of our churches and public institutions. The average American cares no more about the conditions outside the walls of his home than he cares about the conditions on the most distant planet. We are indifferent and unashamed. The spasms of public horror are soon over and forgotten. They accomplish nothing.

This arraignment of the American people applies with equal force to our fire loss and ought to bring the blush of shame to every public spirited citizen.

You are familiar with the idea embraced in the first part of the title of this paper, " Electricity as viewed by the Insurance Engineer ", but do not the foregoing facts and figures warrant the second part of that title and demand not only from the electrical engineer but also from all classes of business men a careful and thoughtful consideration of the subject of fire protection and fire prevention? Should not every member of this Institute join hands with his fellow members of the National Fire Protection Association, and do his part to stop this appalling destruction of accumulated wealth?

" A penny saved is a penny earned " and while the insurance or fire protection engineer cannot create wealth as do the electrical industries, he can endeavor to lessen the unnecessary destruction of created wealth and thereby prove his right to exist. We cannot fairly throw the whole burden of this work on the insurance companies, their profit would be the same if they did nothing to reduce the fire loss and simply made it a matter of rates.

This is true of every public service corporation, but you men know that your best efforts are given all the time to reducing the cost of production, not solely to increase your profits, but because your great desire is to please your customer by giving him better service at a constantly decreasing cost and with a reasonably remunerative profit for yourselves. Do you not believe that the insurance companies are actuated by just as reasonable, honest, and business-like principles?

The market of the stock exchange is known to be the most sensitive barometer of the financial condition of the country. The prospect of poor crops, and therefore a poor year for the railroads, will cause a drop in prices long before the failure of the crop is assured. Are you surprised that the underwriting interests are equally sensitive, when you consider that the combined capital of the American stock companies in 1906 was $60,000,000 and the insurance at risk was $22,000,000,000, that the net surplus of all American and foreign companies doing business in the United States was $147,000,000 and the insurance at risk was $30,000,000,000? A fire in the congested value district of New York covering an area equalling that of the San Francisco conflagration would wipe out of existence nearly every insurance company doing business in that city. Do you not see, then, that it is but natural for such interests to " view with alarm " every newly introduced agent that may affect unfavorably the fire loss? Do you not realize that when the simple act of a cow kicking over a kerosene oil lamp can result in a Chicago conflagration, that the hazard of kerosene oil lamps is a very different proposition from what it would be if such a careless act on the part of that cow could only result in the destruction of the lamp, or, at most, of the building in which the lamp is located?

What must the fire protection engineer know? There is only one answer—he must know something about almost everything, he must be versed in the construction of buildings, in their equipment with fire protective and fire productive devices; he must know the hazards of all the different manufacturing and mercantile occupancies of such buildings. How can a man familiarize himself with every known business? He cannot. That is why he comes to you for advice. His work must be largely critical and that is the reason he is unpopular. He comes to you and asks you to create, and then to submit your creation to him to criticize; and he tells you this or that feature is likely to produce a fire, so he will have to charge an admission fee if you add your creation to his existing risk. This is unpleasant for you and for him too. He has his own troubles without seeking a quarrel with you.

Cannot you work together? Of course you can. Trust him, you are honest; and he is equally entitled to be considered honest. Talk it over, find out how your pet creation can be changed so as to remain just as attractive to you and become unobjectionable to him. It is your duty as a patriotic citizen of this country to do all in your power to reduce the fire loss. Work with him for that reason and because it will be for your advantage; your assistance will be welcomed, even if your prime motive is not love of the critic or of the insurance companies by whom he is employed.

It is my intention in this paper to direct your attention to the work of the fire protection engineer in a little different light from what you might expect from the title; but you must remember that I am here now, not in my capacity as a member of this Institute but rather in that of a delegate from a sister engineering society, the National Fire Protection Association, a society of which this Institute is an active member. I am here to urge you to make that membership active, not only in name but also in fact, as far as you consistently can in connection with your other and regular professional duties.

I can probably never divorce myself in the minds of many of your members to whom I am personally known, from the insurance or underwriting interests, nor would I do so if I could; that is my life work and must claim my best efforts. In connection with that work, this Institute has, I am pleased to say, done able and efficient work, work that has been of great value to the underwriters, and, I firmly believe, of equal value to the great profession which you honor.

This is the first time that the National Fire Protection Association has been formally represented at an annual meeting of this Institute, and it seems to me that the time allotted to me in that capacity could not be better occupied than by endeavoring to show in a general way why there must be a close relation, either coöperative or antagonistic, between the electrical and the fire protection engineer. I could, of course, discuss some particular hazard or hazards of electricity as a fire producing agent, but if I can arouse in the membership of this Institute a sense of the duty they owe, not to the insurance companies but to mankind in general, so that each will give some thought and attention to electrical fire hazard problems, then we can trust to committees of conference to work out the details of each and all of the individual problems as they arise. Such work must always, in its results, be more or less of a compromise, often taking on a single point much more time than could be given here to the entire subject.

About fifteen years ago I suggested to some of the members of this Institute the desirability of active coöperation on the part of the Institute in the formulating of the underwriters' rules. But as this is, and should be a conservative body, it was not until 1896, in the National Conference, that the Institute itself took up this work, although many of its members had given valuable assistance from the outset.

You must admit that electricity may be a most serious fire hazard. The possibilities in that direction can hardly be estimated, and I believe that it was a most fortunate thing for the electrical interests that fire underwriters had begun to appreciate the necessity of fire protection before electricity was introduced for lighting and power, so that they immediately began to surround it with necessary and proper restrictions.

I think that no small part of the progress of your art has been due to the fact that in its early days, when the electrical engineer knew little about the fire hazard of electricity, the underwriter, knowing less but fearing much, appeared as an unwelcome but salutary obstructionist and at least caused the matter to be considered and investigated.

Some of the early fittings and methods of installation certainly would seem to justify any fears that the insurance interests may have entertained. I can remember when, back in the eighties, if the notches cut in floor timbers for gas pipes happened to be large enough, they were considered as a providentially prepared place for the wires, one on each side of the pipe. Now, through coöperation between the two parties in interest, how all this has changed; for I can stand here and tell you from the insurance interests that I believe any undue hazard from electricity has been and is being guarded against. You now give to us the safest illuminant and the safest source of power that we have. We welcome you in that you displace the open flame of gas or oil and the fire under the boiler, that you may by small power units do away with much shafting and the inherent liability of hot bearings. In order to retain this good opinion, however, we must continue our coöperation so that as your art progresses in giant strides, we may together keep pace with it in restrictions which shall not obstruct but safeguard its advance.

My great desire has been and is to foster and encourage this coöperation for our mutual benefit; our interests lie in the same direction, we must travel along together and put up with each others' faults whether we will or not. Shall we not walk as companions rather than enemies? Neither of us has a right to all the good things, nor deserves all the bad things; let us share the good things we each have and help each other with the bad things we must meet.

From the National Fire Protection Association, I bring you all a greeting and an assurance of a welcome if you will share their great work. From the underwriting interests, I also bring you greeting and assurance that we like you better as we know you better; but to the ordinary underwriter you represent a strange and unfamiliar creature, electricity, very difficult to comprehend. You do not know what electricity really is yourself, and how should we? It has served its time as a convenient substitute for our old friends, rats and matches and spontaneous combustion; it has proved its usefulness in many ways to us; it is rather erratic and sometimes inclined to stray from the path assigned to it, but on the whole it has improved so much, as it is reaching the age of maturity, that it is no longer of any particular use to us as a bugaboo to scare people with. Shall we not join hands and work together even more closely in the future than we have in the past?

Discussion on "Electricity as Viewed by the Insurance Engineer. Should the A.I.E.E. Interest Itself in Fire Protection?" Atlantic City, N. J., June 29, 1908

Chas. P. Steinmetz: The matter of fire protection is of extreme importance, and the Institute should certainly actively coöperate with other organizations in the effort to reduce the risk. I believe, however, the question is a far broader one than that of fire hazard. Electrical fire hazard may be of interest to the fire underwriters, but it is equally important that the Institute should consider the danger of electric power to human life, to invested capital, to the destruction of apparatus, etc., even if the destruction does not mean an increased fire hazard. The Institute is the one body which could take up this subject in its broader aspect. I think that the Institute should appoint a committee dealing with such questions. Such a committee may better existing conditions by establishing rules. A safer and better way for the committee to act would perhaps be to obtain papers that reflect good engineering practice, calling these papers to the attention of the public at large. This would be more effective than the formulating of a lot of rules. These papers could discuss the practice of carrying extra high voltage lines through towns and cities and indicate good practice in overhead lines of different voltages, and whether these overhead lines of different voltages should be on the same poles or not. Rigid rules on all these matters cannot be insisted upon, but in a paper an author can readily state his views and thereby bring the matter before the whole Institute for discussion.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

WATER POWER DEVELOPMENT IN THE NATIONAL FORESTS. A SUGGESTED GOVERNMENT POLICY

BY FRANK G. BAUM

In order to insure the supply of timber and to protect the water sheds and conserve the water of our mountain streams, the government some years ago adopted the policy of withdrawing large timber areas from entry by creating national forests. The forests were to be operated by the forestry department for use and not for profit. Recently the government has given permits to companies proposing to make power developments, on condition that the permits be revocable at the pleasure of the Secretary of the Agriculture, and that there be a conservation water royalty charge by the government on the power output of the plant.

Objections to temporary permits have been made by the power companies, as no one wishes to invest money at the risk of losing it through the whim of some official. Objections have also been made to the conservation charge, especially when it is based on the output of the plant. In this paper I shall try to arrive at what I believe to be a logical conclusion of a fair conservation charge.

The matter is of great importance, because power development is advancing the progress of the country at an increasing rate, and a government policy retarding power development will hinder this progress. Power development stands to-day at the same stage, so far as its influence on progress is concerned, as the construction of railroads did 20 or 40 years ago. The immense benefits to be derived from the development of cheap power and the resulting saving of our timber, oil, and coal resources should not be deferred by an unfair government policy or indefinite assurances for the safety of the money invested.

The proper development of water powers would utilize resources now going to waste; the development of coal mines, on the other hand, means the consumption of resources now stored and available at any future time. Every hydroelectric horse power saves the consumption of about twelve tons of coal per year. Therefore the proper development of the water powers would conserve the country's coal resources to that extent. For example, 1,000,000 hydroelectric horse power transmitted to New York and its vicinity for manufacturing purposes would result in saving about 12,000,000 tons of coal per year. This coal could be reserved for domestic purposes. This is about 20,000 cars of 50 tons each per month, or 666 cars per day. The development and use of less than 25 per cent. of California's available water powers would stop all wood, oil, and coal burning for power purposes, including all railroads in that state. The same is true for nearly all the western states and a great many cf the eastern and southern states.

In order to limit speculation, and at the same time to hasten water power development and save our wood, oil, and coal resources, I suggest that all rights-of-way and lands necessary for this development be given on condition that a certain proportion of the work be done each year and that a certain proportion of the development be completed within five years. This would put the man developing the water power on exactly the same basis as the miner and the farmer; it would prevent speculation and limit the operations to bona fide developments. No man or combination of men, no matter how wealthy and greedy, would then be able to monopolize the water power resources of this country. The statement that there is now danger of a water power monopoly in this country is utterly absurd to any one having a knowledge of the facts or the conditions under which water power developments must be made. The development of our water areas would help to conserve the coal areas, and would protect the national forests, where water power is developed, at no expense to the government.

It will be assumed that the object of the proposed conservation charge is not intended as a means to raise revenue for the government, but for the purpose of protecting, operating, and maintaining the forests, so that the greatest possible use may be made of them, not for this year or next, but with the idea of using the forests to produce a perpetual supply of food, timber, water, etc.

It follows as a natural consequence that the different reserve sections must stand on their own merits; that is, the revenues in California, for example, should not be made so great that it would be impossible to use the revenue in the reserves in that section. In other words, it would be only fair that the revenue derived from a California reserve, say, should not be used to purchase, or maintain, a reserve in Maine.

It follows, further, that each reserve unit should stand on its own merits, and the money derived from any one reserve should, as far as possible, be used to maintain and promote the interests of that particular reserve unit. The people entitled to the products of the reserve, who should be given first consideration, would be those who settled in the country, many of them having *settled because of the resources in the reserves* adjacent to their place of settlement. Naturally, they should be entitled to first consideration in disposing of the products of the reserve. Those who settled in a particularly favorable location should not contribute to the reserves of a less favorable condition. This policy is, I believe, followed in giving grazing permits, and also in timber permits.

Coming now to a particular reserve. The reserve has resources mainly in feed, timber and water. The area of the feed and timber product of a reserve has no natural boundary. When we consider the water product, however, we find natural boundaries for each watershed, and logically to arrive at a fair and equitable basis for a conservation water charge we must consider each water shed by its natural boundary, and each watershed as a unit. The man wishing to make a power development should pay only a just proportion of the cost of maintaining the watershed and conserving the water. In a certain reserve, for example, there are two adjacent watersheds. The area of the two watersheds may be the same, and the water output also, but the cost of maintenance of the reserve lands in one shed be entirely different from that in the other; the value of the power resources in the two adjacent watersheds may be entirely different. Watershed A for instance, may, have an area of 100,000 acres, a water output of a certain number of average second-feet, and the power which can be economically developed, say, 5000 kw. Watershed B may have the same number of acres, but the economical power development may be 50,000 kw. On the basis of a fixed charge per kilowatt-year, as proposed, watershed B would give a revenue to the government ten times as great as that of watershed A. The revenue derived by the government on this basis from watershed B from the power resource, is much more than justifiable, considering the cost of protecting and maintaining same, and much more than can possibly be used in that particular watershed for any purpose benefiting the power privilege. It is only fair that the government's charge against the power privilege should be based *on what the government furnishes* to make the privilege operative. The cost of maintenance in the case A might be very much greater than in the case B, yet the revenue derived from B, on the basis of a fixed charge per unit of output, would be ten times as great as the revenue derived from A. Some parallel examples will illustrate the principle of the proposed method of fixing the charge.

The Reclamation Service, in charging for reclaiming lands, applies to each district all the cost equally to all the lands to be irrigated. If one watershed district offers opportunities for developing a project for $20 per acre, that is the charge made, although in the adjacent watershed, or district, the charge may be $40 per acre. That is, the principle is recognized that *the people settling in a particular area are entitled to all the natural resources belonging thereto.* No profit can be made from one area and applied to another. Similarly in power development, the man who develops in one watershed is entitled to all the natural advantages belonging to that area, and he should not be made to pay to help develop power on an adjacent watershed. None of the money contributed by him, because of his privilege, can be used rightly for any other purpose, except to benefit the watershed or privilege which he enjoys. The grazing and timber interests pay their just proportion of the cost to the government of the privileges enjoyed by them, and the power privilege should likewise pay its just proportion.

Suppose again that the government withdraws a given timber area in order to assure ties to several railroads that traverse it. What is a just charge for the ties? A charge on the gross or net revenue of the road, or a rate on the tonnage passing through the reserve would be absurd; the only fair charge would be on the value of the ties, calculated on the yearly expense of maintenance and the number of ties the reserve can produce annually. Why then should the water-power company pay a royalty on the basis of its power output? The grazing and timber interests are not taxed with the idea of producing a profit to the government, or that the grazing or timber interests of one section should support those of another, or that these interests should be taxed to support others. The miner is not charged a royalty by the government, but the government can rightly charge him for any direct benefit he may receive by reason of the reserves.

By all precedent, then, the principle is well established that the government should calculate the cost of what is furnished, and the conservation charge be made accordingly. This would establish the principle that the annual conservation charge should be based on the actual yearly cost to the government of the cost of conservation. The conservation charge would change from time to time, but there would be a definite basis for its determination.

Rights-of-way on lands occupied for reservoirs, pipe-lines, and power houses should be sold to the power company at a fair value, and these lands would not then enter into the determination of the conservation charge. Rights-of-way and lands necessary for the development should be the property of the company. These matters should be fixed independently of the conservation charge. We should not expect railroads to open up new country if their rights-of-way were revocable, or if they were charged on the basis of tonnage carried over the right-of-way.

Coming now to the analysis of a particular watershed and the privilege granted to the power company on it: the withdrawal and protection of the timber will generally affect the stream-flow, and a just charge can be made by the government for the protection given, as it directly benefits the privilege. The charge made for the protection of the timber and the stream-flow must naturally vary with the conditions, and must be calculated for each case, because other interests should also pay their just charge for the protection. The charge made for the reservoir privileges, rights-of-way, for canals, pipe-lines, and power-house sites should, however, be based on the value of the acreage occupied. Because a power development occupies a given piece of ground, makes it no more valuable to the seller (the government) than if it were to be occupied by a quartz mill, and the power man should pay no more than the miner or any other interest.

When the amount to be charged for the right-of-way, reservoir, and power-house sites is fixed, and the government has determined the amount to be expended yearly on the watershed, the amount to be charged for the power privilege can be easily fixed. It should make no difference in the charge whether 5000 kw. is obtained in power, or 50,000 kw. That is, as in the case of the farmer and the Reclamation Service, the man settling in the valley where conditions are favorable for low cost of irrigation should have the benefit of that condition. And the power man who uses his ingenuity and money to discover a better power development than another should also have the benefit of his enterprise. The government has not yet, and I hope never will, put a tax upon discovery, invention, and development.

Still further to show the reasonableness of a fixed total charge annually for a given watershed, we may merely cite the fact that if the charge is based on the kilowatt output, the man who puts in a cheap and wasteful system pays less than the man who puts in a more expensive and efficient system. Further, the man who sells his power for $20 per kilowatt year, pays double the percentage paid by the man who sells for $40 per kilowatt-year. And again, the man who takes this power to a market, say 100 to 300 miles away, must pay to the government for the losses and expense in doing so and pays more than the man who sells to the home market. The man who reaches out with his power is equalizing conditions, just as railroads equalize conditions by their transportation facilities, and should be encouraged and not taxed for doing so.

Coming to the case where the government owns part of the property necessary for the conservation and development, and part is owned by private parties, or the man making the development. For example, assume that the power company making the development owns a reservoir which controls the stream. Assume that this reservoir is the controling feature of the development, that without it the stream is virtually worthless. It may even be that the reservoir is all that is necessary, and the protection of the timber could have no effect on the development, and its removal would not affect the development in the least. Has the government a right to make a conservation charge when as a matter of fact the man is paying for his own conservation? In this case the government can only charge for rights-of-way and lands occupied, and no conservation charge can be justly made. If the government furnishes part of the conservation—this is usually the case—then a proper proportion of the basic rate of the conservation charge can be made.

This may be illustrated by taking the case of a man owning a timber area to which he had title before the establishment of a reserve. In order to make use of the timber it is necessary to obtain from the government land for a mill-site and right-of-way for a railroad from the timber to the mill-site. A proper charge for the land for the mill and right-of-way can only be made on the basis of the value of the lands occupied. A charge on the output of the mill would be entirely unjust; this will be admitted by all. Change the timber area to a reservoir, the mill-site to a power-house site, and the railroad to a pipe-line, and wherein lies the difference? The man purchased the reservoir before the reserve was established, to store water and develop power. In order to do this he must have the right-of-way for pipe-line and land for power-house site, and these must be granted him as in the case of the sawmill, on the basis of the land value, and not on a royalty of the power output. No royalty should be charged for giving the man the only opportunity there is to make use of his property. Any number of parallel cases could be cited to illustrate the principle. In creating a forest reserve the government cannot but recognize the rights of private individuals or companies who owned lands in the reserve previous to its establishment, and the government must allow owners the use of their property. Any other course would amount to confiscation.

The above suggested method of fixing the conservation charge is believed to be logical and treats the power interests as others. The amount to be charged yearly for conservation would be influenced by only one fact; that is, the yearly cost to the government of maintaining the area benefiting the privilege, and what proportion of the charge should be borne by the power company? It eliminates all questions as to the efficiency of the development or the amount of development, and *hence would tend to make for efficiency and maximum use of the resources.* It eliminates the question of the market value or distance of transmission. The market value would, as it should, depend upon the natural advantages for power development in the district, and there should be no additional tax when high efficiency is aimed at or long transmission is undertaken.

Rights-of-way and property necessary would be a separate matter from the conservation charge, and property rights necessary for development would be not temporary but permanent. We should not expect a man to establish his permanent home and develop his farm if he is not assured title.

The above method of charging separately for lands and for conservation, and giving title to lands, would remove all objection on the part of investors, because then power companies would obtain title to grounds occupied by the development and there would be a definite and fair method by which the conservation charge would be arrived at, now or at any future time. It is believed no logical objection could be raised to the plan by the power companies.

It may be contended by some that the government should obtain as large a revenue as possible for every development and apply the proceeds for the general welfare, the argument being based on the fact that the government grants a privilege which cannot be enjoyed by others and should receive a revenue in proportion to that derived from the operation of the privilege. The examples cited, however, make this position untenable, as the power companies should not be treated differently from the farmer, the miner, the lumber company, the railroads, or other interests. There is no monopoly in water power development, and the advantage gained by a man who does something should not be shared by the man not so progressive. It would be just as logical to make the thrifty farmer share with the less thrifty. Industry, progressiveness, and individuality should not be stifled or taxed.

Feed, timber, all crops, minerals, water and water products, and anything which nature produces, are primary producers of wealth. Why should water be classed differently from any of the other natural products in the government policy of development and control? *The general government cannot justly make a charge equivalent to a franchise tax or regulate rates; those privileges would remain with the state and subject to local laws, where the streams are under state control.* My understanding of the law is that all streams, except those that are navigable, are under state control.

When the conditions of the past, present, and future developments of the country and its industries are considered in relation to the present and future developments of power, it is believed that the only tenable conclusion which can be reached is that the power interests must be treated as other interests and *charged for conservation only on the basis of the cost to the government of the thing furnished by the government*, and that rights-of-way and property required for the development should be the property of the company making the development. The only varying element, then, will be that due to the fact that the value of the property owned by the government is changing as time advances, and the conservation charge should be changed accordingly.

The conclusions drawn from the above discussion may be briefly stated as follows:

1. Rights-of-way and lands necessary for the development should be charged for on a fair basis of value, as would be determined if the lands belonged to private parties and a value had to be set on them for the power purposes by a court, or a commission. Rights-of-way and lands necessary should be deeded outright by the government to the power company and the only changing conditions then, as time goes on, would be the yearly conservation charge.

2. A proper conservation charge can be made only on the basis of the cost to the government of that which is furnished by the government.

3. The right to charge a privilege or franchise tax should remain with the state and subject to local laws as conditions warrant.

A. The conservation charge will have a maximum limit at any given time which can be determined by calculating the yearly cost of the conservation to the government. This charge can be fixed for a period of say ten years, and at the end of that time a re-calculation may be made, and a new conservation charge made yearly, to meet the changing cost of maintenance.

B. The proceeds from any particular privilege should not be devoted to any other watershed or any other section, or for any purpose except the particular privilege.

C. The question of the proper conservation charge is entirely a separate matter from the charge to be made for lands and rights-of-way for development, and the two matters should be kept distinct.

My suggestion for a government policy on water-power resources can finally be stated in a single sentence—encourage water-power development as much as possible, make a proper conservation charge, based on the cost to the government, and make grants for rights-of-way and lands necessary for development permanent on condition that a certain proportion of the work be done each year, and that a certain proportion of the development be completed within five years when a patent for all grounds occupied will be granted, reserving to the states the right to charge a privilege or franchise tax as the conditions warrant.

Discussion on "Water Power Development in the National Forests. A Suggested Government Policy." Atlantic City, N. J., June 29, 1908

J. H. Finney: Mr. Baum's paper is an interesting presentation of his views as a "power enthusiast and a believer in a cheap source of power," and his belief that "cheap power is vital and necessary to the present and future development of the country" will be, I am sure, supported heartily in this assemblage. We may also be classed as power enthusiasts. I think, however, that his presentation of the case is wrong from several standpoints:

1. In considering the national forests, wherever located, in the light of a local asset and not as a national asset, in which all the people should share.
2. In basing a power charge or franchise solely on the cost of forest conservation and not on the value of the grant fixed by the earning capacity.
3. In the attitude which assumes that a policy other than that outlined by him would put a tax on discovery, invention, and development, by ascribing to capital and genius, seeking legitimate investment and fair returns, attributes that indicate a selfishness fortunately not always true.
4. By a disregard of what might be termed the "rights of the people" in and to an asset of perpetual value, national and not local in character, a value that increases from decade to decade, as coal becomes scarcer and dearer.

Let us first see what the government's stand is on the question of charges. It can best be stated in a general way by quoting President Roosevelt's specific statement before the recent Conference in Washington.

> My position has been simply that where a privilege, which may be of untold value in the future to the private individual granted it, is asked from the federal government, that the federal government shall put on the grant a condition that it shall not be a grant in perpetuity. Make it long enough so that the corporation shall have an ample material reward. The corporation deserves it. Give an ample reward to the captain of industry, but not an indeterminate reward. Put in a provision that will enable our children at the end of a certain specified period to say what in their judgment should be done with that great natural power, which is of use to the grantee only because the people as a whole allow him to use it. It is eminently right that he should be allowed to make ample profit from his development of it, but make him pay something for the privilege and make the grant for a fixed period, so that when the conditions change, as in all probability they will change, our children, the nation of the future, shall have the right to determine the conditions upon which the privilege shall then be enjoyed.
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> Where that policy can best be carried out by the state, carry it out by the state; where it can be best carried out by the nation, carry it out by the nation. My concern is not with the academic side of the question; my concern is in the employment either of the principle of states rights, or the principle of national sovereignty, as will best conserve the needs of the people as a whole.

This is a clear statement of a just and righteous intent, and who among us will question its honesty, or the wisdom and desirability of its proper and successful accomplishment? This policy has, I believe, been more specifically elaborated by the Forest Service in certain cases, involving governmental grants as a definite policy, namely:

(*a*). The charge for power permits should be based on the power value of the land occupied and the value of the services rendered by the government.

(*b*). The proceeds from any particular permit may legally be appropriated by the Congress for any public purpose, and, under the same policy, may properly be used for the expense of administering in national forests, or for the reclamation fund, or for the proposed inland waterways fund.

(*c*). The plan of calculating the maximum conservation charge upon the yearly cost of forest conservation to the government would be impracticable, for the additional reason that such cost ought to be vastly higher than it is now. In the European forests the cost is several dollars per acre, as against one cent per acre this year in this country.

(*d*). The question of the charge for power plants is a unit. In considering it, the rental value of the land and the value of the services rendered by the government in forest conservation should and must be considered together.

(*e*). The rental value for power purposes of the lands occupied should be paid by the permittee, not merely their value for forest purposes, farm purposes, and the like. The government is entitled to their value for all purposes, especially including the purpose for which they are actually occupied. This value must be fixed by the administrative officers of the government at such a rate as will encourage the taking of permits. But the government should retain permanent ownership, subject to the temporary right of the permittee to use the land.

(*f*). Practical considerations of administration make it desirable that the charge for power plants should be uniform. It has therefore been fixed at a rate which is believed to be sufficiently low not to check the development of any project.

While this policy may not be yet fully worked out, perhaps may not be the final word, it is, I maintain, in exact accord with the views and policy which the President seeks to establish, which in its final analysis is simply equal justice to both grantee and grantor, in rights which involve the use of the common property of the people as a whole, rights which are in their strictest sense, ours only as trustees and guardians for the future.

It may not be amiss to say here that this idea of trusteeship, while not strictly new, has in the past few years attained a new significance; and there are evidences of an awakening of the public conscience in respect to our guardianship and to our obvious duty to ourselves and to posterity in these matters that betokens a better America. The whole conservation movement, crystallized by the notable conference just held at Washington, marks, I believe, a new era in American thought and American habit.

Forests as a national asset. The national forest in the West is the heritage of the whole people. No state or local boundaries were in the mind of the Almighty when the forests were first planted by him. No state boundary now confines their use or benefits or value to the state alone. The California forests serve other states in water conservation, in water power, in climatic effects, in supplying timber, grazing, etc., and the same is true of forests whether located in Wyoming or Washington or Idaho. They are public domain, belonging to the nation, not to the states containing them. They are, therefore, in all the benefits and profits accruing from them, the common property of the nation. The state fortunately containing them gains the greatest benefit, and rightly so, but no claim that they are the exclusive property of the state as regards benefits or profits is tenable. The nation is the sovereign, and as a matter of fact and right the profits from them, while in part shared with the state, are converted into the national treasury. They should be turned into a forest fund that could be used to establish other national forests.

In the east where the Appalachian national forest is projected, and so badly needed, the situation is different only in degree. The states agree to relinquish sovereignty, the title passing by purchase to the new owner, the federal government. The states will get their share of profit—the balance goes into the treasury. Nor can the forest here be considered a local asset. The states are manifestly unable to act effectively in its establishment. The very fact that the national government must act shows its interstate, its national character.

From the forested mountains of North Carolina flow streams that make power and navigation possible in streams in adjacent states—north, south, east and west. Some twenty states are directly, and the whole nation indirectly affected by what North Carolina does, should she denude or preserve her forests. It cannot be considered, therefore, as a local question, and I think Mr. Baum's view is narrow and untenable. Does the San Francisco post office expend its surplus only on San Francisco's postal service, or the New York post office on New York's? Is not the profit from these larger and more prosperous centers used to improve the efficiency and value of the postal service as a whole to the whole people?

Let us look into this a moment. The government at present sells the timber on the basis of its selling value, because the timber costs have been to the present time practically nothing, except the small value of the land set aside, and the maintenance and patroling and similar charges. We have not begun to spend on our forests the amount of money which they should have yearly for a definite reforestation policy. Will Mr. Baum advocate this charge against the power company, should we spend, as we some day must, large sums for reforestation?

The national forest, so far as the timber is concerned, was operated at a loss last year. Other forest products considered, there was a substantial profit, and this profit is increasing year by year, and rightly so. Forests become without impropriety a profitable investment to the government, without imposing any purposely designed hardship on the grazer or lumberman or miner or homesteader. If the government has instead of grazing privileges, or lumber, a water power to dispose of, in what respect does it differ from the other forest products? Is not its value what it is worth to the grantee, whether it be five thousand or fifty thousand kilowatts, and is not this value fixed solely by what it may be able to earn as a return on the investment? The 5000-kw. plant may be just as able to earn a fair return as the 50,000-kw. plant. The promoter or the developer might prefer the larger plant, perhaps, as offering more chance for profit, just as a street railway in New York might be a more attractive enterprise than one in Atlantic City, and yet both New York and Atlantic City have street railways, and it is barely possible that the smaller one is the more attractive investment.

It is largely a commercial problem. The 50,000-kw. plant would not be developed if no profitable market existed, even if there were no charges imposed by the government. Commercial considerations govern. There are plants operating and making money where fixed charges are abnormally high, costing $200 or so per kilowatt installed, and selling power at a low price, too; there are others that have cost $80 or less per kilowatt installed that are selling power at a higher rate than the other plant. They all fix what is claimed to be a reasonable charge for current, under the conditions existing in their particular field, and this charge varies quite as much and as radically as the installation costs. It is a reasonable charge at one cent per kilowatt-hour, or two or more, depending on local conditions. We cannot well object to a metered tax on production when we are at the same time through our public service companies, such as the power company, the telephone company, the gas company, and the water company, strenuously and persistently advocating a metered charge for consumption. It is not possible to impose an equitable tax in any other way.

The plant that has so narrow a margin between success and failure as to be seriously affected by the imposition of a fair tax, whether this tax be 1/1000 cent, or 1/100 cent per kilowatt-hour, or even more, perhaps, has small prospect of attracting investors. It is not at all impossible or difficult—we are doing it every day—to get at exact figures of development costs in any project contemplated, and accurately to estimate its earning capacity. We are doing the latter, too, every day. One needs only to recall the engineering reports of the past and the present to see that it is done on the basis of "what the traffic will stand," nor is there impropriety involved in this. When this is done and the property cannot stand a reasonable tax on its output, that project is not a commercial one at the present time and under present conditions, and must await development, as does many another, until a more favorable season.

A tax on discovery and invention. There are no inherited or inherent rights in capital privately to exploit our remaining resources in mines and lands and forests, although this statement seems unduly optimistic in the light of past history. The Americans are over-patient and have been over-exploited, to put it mildly. There may be no power monopoly contemplated, though a water power company is by nature a monopoly *per se*. It is many times the only possible source of supply of a given market. The opportunity for monopoly unquestionably exists in many places now, and there are some striking examples of what might happen to water power in what has happened in the past in some notable combinations of certain railway and other large interests that can be readily recalled.

The government imposes a tax to-day on inventive genius by charging for a patent—the child of one's brain—a uniform charge regardless of the cost of maintenance of a patent office. It fixes also a limitation of the grant to seventeen years—but the Patent Office is full.

No fears are justified, however, that the imposition of a tax, which would net him forty-nine per cent. instead of fifty per cent., or five and nine-tenths instead of six per cent. on a solid investment, will curb either the American's ingenuity or his inventive genius, or his discovery of the quickest way to get the forty-nine per cent. or five and nine-tenths per cent., if he cannot have the larger returns.

Disregard of the people's rights. The real ownership of these natural assets in mines and forests and soil and water clearly lies in the people as a whole—a part of the nation's heritage, whether natural or artificially created through governmental agencies. Some profit therefrom belongs to the people, just as clearly and on the same broad ground as that some profit belongs to the capital and brains developing them. With this right of the people to profit, there exists and there is imposed the duty to fix reasonable restrictions on their use. Rights to exploit them properly should be granted on the basis of a definite term of years for the franchise; a definite basis of fair charge on the output; fair regulation by the government—a policy that is embraced in what is termed "a square deal" to all concerned; to the investor, to the corporation, to the power user and to the nation, and, incidentally, to posterity.

As engineers, knowing better, perhaps, than any other class of observers the immense potential value represented by forty trillion cubic feet flowing annually within our borders, descending an average of twenty-five hundred feet to the sea, and what it means to present America and its future value to future America; dimly realizing the infinitely greater value and incalculable good of our waters in the light of the new concept of them in their substance, or corpus, we cannot go on record as indorsing any plan involving their exploitation and use, that does not have strictly in mind, not only their fullest development and conservation in the largest sense for power, for soil, for water supply, for the health and very life of the people, but the plan must be one that will do equal justice to all and contain special privileges to none.

No less an authority than Jefferson declared that " the earth belongs in usufruct to the generation at any time living upon it." This view is as true to-day and as free from demagogy or socialism as when uttered. It is plain common sense and common honesty, and we as a people are at last beginning to realize it.

E. R. Taylor: I would like to see Mr. Baum's paper broadened out, and my criticism is mostly upon paragraph B, in which Mr. Baum says:

> The proceeds from any particular privilege cannot be devoted to any other watershed or any other section, or for any purpose except the particular privilege.

I had the honor to read a paper on " Forestry, Water Storage, Power and Navigation " before the American Electrochemical Society a few weeks ago. In that paper I think I advocated the converse of that advocated by Mr. Baum in paragraph B. I said there:

> Let each state or section develop one or two streams completely with forest and lakes (and even farmers' tributary brooks to be paid back at cost) as illustrations, and put them to work earning money to develop others later. Let coöperation be the watchword. Private interests cannot do it as it ought to be done; public interests must do it, and the doing will be immensely profitable and a benefit for all coming time.

All of us realize the great value of these water power privileges, if they are rightly developed, and I suggest that all who are interested in the subject get a copy of the Third Annual Report of the New York State Water Supply Commission, which deals with this subject.

P. P. Wells: I desire to explain briefly the forest service policy with regard to what used to be called the conservation charge. I am not a trained engineer and must ask your indulgence on that side of the question. The service is very much indebted to Mr. Baum for the careful consideration he has given this subject. However, we agree with the conclusions that have been expressed by Mr. Finney.

Mr. Baum's paper does not clearly distinguish between the policy of Congress and the policy of the Service—the Administration. Of course, to find out about the policy of Congress we seek the statutes. In respect to the policy of the Forest Service as an administrative body I wish to say something about what its intentions are, what it has done, and what it would like to do.

In the first place, it does not like the present system of having permits for water power development revocable at the discretion of the secretary. That condition is imposed by the Act of Congress of February 15, 1901, in which it is expressly provided that they shall be revocable. The Forest Service would like to have authority to issue permits which would be irrevocable except for breach of conditions, for terms sufficiently long to guarantee security to the investor and a chance for full development.

At Mr. Pinchot's suggestion there was included in the Agricultural Appropriation Bill pending before the last session of Congress, a clause which would have given power to issue irrevocable permits for a term of fifty years. That clause, like all new legislation in appropriation bills, was subject to be stricken out upon a point of order raised by any one member of the House of Representatives. Two members made the point of order against this clause, and it was consequently stricken out.

As the law now stands, the service has gone as far as it can to give permanence. It cannot take away from the successor of the present Secretary of Agriculture the power to revoke the permit. It does, however, specify precisely, before construction begins, the maximum charge that is to be made in every case. This is fixed in every permit for a term of forty years, so that the service has gone as far as it possibly can to give certainty.

Secondly, for the reasons explained so well by Mr. Finney, the service stands for the permanent government control of its great natural resources, and as each fifty-year license expires, new conditions may be then imposed in accordance with the changed circumstances that face the men of that time.

Thirdly, the policy of the service is that no permit which is issued shall be held unused. Pressure is put upon the permittee to make full use of his permit, first, by making a preliminary small acreage or mileage charge pending construction; secondly, by fixing in the permit a specific time in which construction must begin and another specific time in which it must be completed. That time will be extended at the discretion of the Forester, if unforeseen physical obstacles are met with.

Fourthly, the service stands for a uniform small charge or annual rental based on the amount of power developed. The justification of this charge, as Mr. Finney has explained, is that the title of the government to lands in the national forest is unquestioned and absolute. They belong to all the people of the nation. Whatever value there is in them belongs to all. If you consider this value, there are three elements in it, bearing on this matter, which we may call the land resources and the services rendered by the government. In these cases, with respect to water power, the "resources" of the forests may be taken to be the water alone, considered apart from the land itself. Our charge is not based on this element at all. The appropriation of water is made under the state laws. The second element is the value of the land as a power site. It is obvious that one piece of land may be very valuable for that purpose, and another piece of land less valuable, because either of advantageous reservoir sites for storage purposes, or because of a greater fall or head. The third element of value is the service of the government in maintaining a steady water flow by forest conservation. This last is the only element that Mr. Baum's paper considers.

In my opinion, Mr. Baum's analogies do not bear out his arguments. In the first place, it has been for many years the policy of the government to give free homes to settlers, and in furtherance of that policy the government irrigates arid lands at cost for homestead settlers. The present administration does not believe that that policy should be extended to large corporations, who use the public resources primarily for gain. So there is a broad distinction between the homesteader and the commercial user of natural resources that belong to the government.

Take the case of the mineral fuels. Two years ago the present administration definitely announced its policy as that of a lease system, rather than the present system of alienation of coal and oil lands in perpetuity. Take the case of railroad grants and free rights-of-way for railroads; that policy was initiated when the resources of the country were thought to be inexhaustible, and when the Pacific coast had to be connected with the East for political reasons. But the reasons for that policy no longer exist and they do not apply in the matter of water power. Take the case of timber. Timber is required by law, under Act of June 4, 1897, to be sold at public auction to the highest bidder, without regard to the cost of administering the particular forest on which it is sold. Railroad ties, which Mr. Baum's paper mentions, could only be sold in this manner, without any reference whatever to the cost of forest conservation. Grazing fees on the forests are an attempt to approximate the grazing value of the land. So with mill sites; if a man wants a saw-mill site, as Mr. Baum mentions, we vary the charge precisely in accordance to the capacity of the mill. Thus all the analogies, except that of the homesteader, are against the position taken by Mr. Baum.

A word as to what Mr. Baum says about deductions from the charge on account of private ownership of land. It is a settled part of the policy of the Forest Service, that if a power plant occupies unreserved public land, over which the Forest Service has no jurisdiction (private land), a deduction will be made on that account, provided the patent by which the private land was acquired did not reserve to the United States a right-of-way for canals, etc., constructed under the authority of the United States. All patents for lands west of the one hundredth meridian, issued since the Act of 1890, do make such reservations.

Then as to water storage; the policy of the service is to encourage the conservation of water by storage, done by permittees, in such manner that they will not be charged for the conservation of the water they store. They will, however, be charged for the head which they get from the use of the forest lands, which makes this stored water valuable to them; in other words, there is a fifty per cent. reduction from the maximum charge on account of power produced by stored water which would not be produced by the natural flow.

In respect to what Mr. Baum says concerning the reward which should go to the enterprising discoverer of the best power sites, a uniform charge is made, believed to be low enough not to obstruct development on any practicable site. It therefore leaves a wide margin of profit for the enterprising discoverer of a better site, and that margin is the wider as the site is the better.

A. H. Babcock: Paragraph B of Mr. Baum's paper has caused considerable discussion. It is my opinion that Mr. Baum had in mind the fact that in the case of a water power development, the power must be utilized within a limited area. The consumers in the area must pay the government charge; hence they are entitled to the benefit. The charge should be made as low as consistent with the development of that district. Mr. Finney's analogy to the post office charges being distributed for the benefit of the whole country does not seem to me to be a happy one, foı the reason that a two-cent stamp must carry the service into rural districts and other places, where an adequate delivery system otherwise could not possibly be maintained.

President Stott: Some very important points have been raised in the paper and discussions, which I would hear brought out at greater length.

C. P. Steinmetz: I hardly need to say that I thoroughly agree with the opinion, that the preservation of our national resources is a most important problem requiring energetic and prompt action. I am sorry to say, however, that with regard to the methods proposed by Mr. Baum I must disagree in almost every particular. The first argument made by him is that the different water power developments should stand on their own merits; that is, that the proceeds from any particular privilege cannot be devoted to any other watershed, or any other section, or for any other purpose except the particular privilege. He contends that the development of the watershed should be considered as a private matter in that particular locality.

I do not agree with that suggestion, as I believe that, if followed out, it would defeat the very thing we are trying to bring about. It is the same argument which can be made, and is being made, against setting aside and preserving these national resources, that they are not of general, but only of local interest. It is of no benefit, it is claimed, to the Central States, to set aside the Appalachian reserve, or the White Mountain reserve, and therefore the Central States say they do not want the national government, to which they contribute, to pay for doing it.

That is Mr. Baum's argument, but I believe his argument is wrong, and there is a contradiction in the very statement, which Mr. Baum has overlooked. He starts his paper by speaking of the preservation of the *national* resources, and then he says that these resources are only of *local* interest, and should be developed and paid for locally. If they are of local interest only, then they do not need the aid of the national government, but should be left to local enterprise. Under such circumstances I should prefer to leave them to private enterprise. The only reason for calling on the national government is that the subject is not of mere *local* interest, but of *national* importance.

It may appear at first sight immaterial to California whether the water powers of Maine are developed or not, but if the failure to develop the water powers in Maine results in an increased consumption, say, of one hundred million tons of coal, the coal famine resulting will increase the cost of pig iron or structural steel to California as well as to Maine, and so one part of the country will suffer by the destruction of our national resources, by the waste of our national capital, equally with every other part. Hence it is not a *local*, but a *national* problem.

If the problem were merely to develop water powers, then indeed it would be local; but the problem is much broader, it is the problem of preserving and protecting our national capital. Suppose for the sake of argument the cost of the development of the water power is charged to the individual location. Then there would be developed only those watersheds where the cost is lowest and the power greatest; that is to say, those cases where government aid is not needed, as private capital would sooner or later do the developing. But then the far more important problem would remain untouched; the problem where the watershed requires to be protected and would not be protected by private capital, because there is not enough power available in it to justify such protection. The destruction of timber and the erosion of hillsides at every rainfall would very soon be disastrous to the entire country. No effective protection or development can take place when this matter is considered as purely local. Such a policy would be very inefficient in carrying out our purpose of protecting and preserving the national resources, and would indeed be the surest way of defeating this purpose. As long as it is a national problem, the nation stands or falls as a whole, is responsible as a whole, and has to take care of it or benefit by it as a whole.

Whether the payment for the work is made by the United States treasury, or by assessment on the beneficiaries of the development of the national resources, whichever it may be, remains for discussion, but certainly we cannot consider the development as a matter only of local importance.

Furthermore, it would be just as unfair to charge a high power cost to a moderate water power which may be very valuable and necessary, merely because the development of its watershed was rather expensive, while another water power may be developed almost free of charge where the watershed required very little attention. A part of the argument of the paper is that the proposed method of charge by the kilowatt output is unfair. Granting that, it should not be concluded that any other method proposed by the writer is therefore the proper method. If one proposed method is unfair, it does not prove the correctness of one other method; it merely means that we should find a fairer method than that which is proposed.

I agree with the writer that a fixed charge per kilowatt may not be fair. One thousand kilowatts of power developed near New York City is vastly more valuable than 5,000 kw. of power developed five hundred miles from nowhere. You may say we make the charge so low that every one needing the power can afford to pay the charge. That is unjust again, because we then fail to make a reasonable and fair charge on the profitable water power near New York City, and therefore fail to derive as much revenue for use in developing resources as the development of water power can stand.

The last point I desire to discuss is the feasibility of Mr. Baum's proposition, that the franchise privileges must be perpetual. He claims there is no franchise or privilege, but that the matter is the same as if I buy a piece of land and build a private residence. In the same manner those which develop the water power should buy the land. He does not believe in this argument himself, however, because in other parts of the paper he uses the term " privilege " and so signifies that there is a little more involved than buying a plot of land for a private residence. However, whether we think it desirable or not, we must realize that there is a very strong and growing sentiment against perpetual franchises, against giving away national property in perpetuity, or even for a long term of years, such as ninety-nine years or fifty years. Whether this is desirable or not, we must realize that the sentiment is growing and will not reverse, and will have to be dealt with as a fact, whether we like it or not, so that it will be increasingly more difficult to get perpetual franchises or privileges, or even long-term franchises. Whatever arrangements we so recommend, we will have to count on this condition—the lifetime of a franchise will be the lifetime of a generation, or something like twenty-five or thirty years at the most.

There are thus two features which we must keep in mind; to develop and protect as quickly and as completely as possible our national resources in forests and streams and mines, and to make the development such as to induce private capital to enter into it. The problem which we have to solve is how to combine the short-term franchise with such conditions, so that private capital will invest in these water powers.

Now to induce private capital to enter this field requires that capital must be guaranteed against confiscation, direct or indirect; that is, there must be a guarantee that at the termination of whatever franchise there is, there shall be no confiscation, that the value of the plant shall be preserved as a tangible asset of the investor. As soon as we guarantee that, I do not see that it matters very much whether the franchise is perpetual or whether it is relatively short, the only just objection against a short-term franchise is that the investor has to face the condition that he must get his full capital returned with interest within seventeen or twenty-five years, because he has no guarantee or protection of the investment beyond that time. The value of the investment must be guaranteed in any limited franchise.

There is however a franchise or monopoly very much stronger than any other franchise ever dreamed of by anybody, whether a water power franchise, or a city railway franchise, or anything else. The strongest indeed of all privileges, franchises, or monopolies is the manufacture of a patented invention. There is no restriction; you may develop the invention or not, you can give the public the benefit or not. You can throw it away, and no one has any right to object. You can charge ten thousand per cent. profit if you choose, but after a limited time, seventeen years, this monopoly expires. But there is no confiscation. Whatever factories, whatever plants you have erected to carry out this invention, they are still your property, except that now this invested capital has to compete on even terms with all other industries; that is, it is entitled to a fair rate of interest, but no more fancy profits. So I believe some similar method could be developed for the similar problem of creating values, where values did not exist before, in the water powers, forests, and mines, and *unlimited* franchises for a limited time; that is, unlimited regarding restrictions, price, time of development, etc., might and should be given, because it is necessary to have the possibility of unlimited profit to compensate for the chances, which are not small, of complete loss in the failure of the power development. But that should be for a limited time only, say the same seventeen years the letters patent has to run, and after that time the franchise expires, and either the government can take over the plant at its actual value, or renew the franchise with such restrictions, limitations, or conditions, as may seem to it desirable, provided these conditions do not constitute a confiscation of invested capital.

I think this would take away the reasonable objections to the short-term franchise, and would make it feasible, by holding out chances of very large returns during the unlimited period, to take the risk of complete loss. After all, this idea of the water powers being very valuable is a misconception, derived from looking at those powers which have been a commercial success, and forgetting to look at those many other franchises, city railways, etc., which have been developed and capital sunk into them without return.

The development of a water power is just like the exploitation of a letters patent, in the fact that the success of the two is a matter of some doubt—they are properties of questionable value. The water power may be, when fully developed, of extreme value, or it may be an entire loss. It is not an unquestionable asset, like United States bonds. If you desire to get the water powers developed, and desire to interest private capital therein, you thus cannot expect to limit the returns to the moderate values of the usual conservative commercial enterprises, because you cannot limit the chances of failure, and where there is a chance of loss you must compensate for it by the chance of more than normal gain or profit.

Wm. McClellan: I think we all agree that the word "national" strikes the keynote of this whole discussion. Those who realize the importance of this badly misunderstood question, and have taken the trouble to investigate the conditions, have found opinion is very likely to vary according to locality. In various parts of the West and South, great water powers exist more or less in their natural state. Whatever deficiencies or irregularities they have are natural. When we come to the East, however, we find a large number of valuable water powers which may be called "spoiled water powers." This has occurred on account of the denudation of forests at the head waters. During this last winter I have had occasion to examine a number of these eastern water powers, many of them of comparatively low head. It is surprising to find how many places there are where not more than 500 h.p. can be developed at present, and yet records show that years ago, before natural conditions had been changed, there would have been at times as much as 5000 to 6000 h.p. Steps are being taken by several state commissions to determine plans and the cost for overcoming these deficiencies by making the flow of the river as uniform as possible throughout the year.

These great natural water powers of the West, needing in many cases comparatively little assistance, and the great spoiled water powers of the East, needing in some cases a large amount of assistance, all make up the heritage of the nation. The fallacy is very subtle, nevertheless it is an absolute fallacy, that these resources should be developed for the benefit of the immediate community or state. In the opinion of the speaker, these resources should be considered as a whole, and charges for development and assistance should be made in every case from the standpoint of general utility. The government, like an individual, should so manage its resources that all are brought up to as efficient a condition, with as great earning capacity as possible.

It is for engineers to say whether a good water power is a real asset of the government, and is worth developing. They are best fitted to examine the local conditions in each case, and see what change is advisable for a water power.

It is safe to say also that if this matter is not taken up on a national basis, there will be difficulties later, inasmuch as a large part of the water power of the country exists at present in locations which come under the national government, and in many other cases, where strictly speaking it is a state matter, attempts will be made to transmit power between the states. This will probably become a matter for national control some time later.

C. H. Porter (by letter): It seems to me that every one who considers this question must agree with Mr. Baum that the regulations of the government with reference to the granting of power permits in national forests should be such as to encourage the development of water powers and that the present regulations are unsatisfactory. That the Forest Service recognizes this is shown by the following extract from a letter signed by Mr. Pinchot, and dated May 5, 1908:

> I wish to say now that I have never advocated revocable permits. The Act of February 15, 1901, expressly requires that all permits shall be revocable. I have consistently advocated legislation to authorize the issue of permits irrevocable for a fixed term, which should be sufficiently long to give reasonable security to investors—say fifty years. During this term the permittee, so long as he fulfils the conditions expressed in his permit, should be as independent as the holder of any other property. Moreover, the conditions of the permit should define with as great accuracy as possible the maximum burden placed upon him. He would then be in a position to solicit investment in his enterprise by offering certainty and security to the investor.
>
> For these reasons I secured the insertion by the House Committee on Agriculture in the agricultural appropriation bill, now pending, of a clause authorizing the issue of irrevocable permits for fifty years. This clause was stricken out in the House. I believe that it would have been enacted into law if it had received the support of the friends of the power companies and that the companies have themselves only to blame if they are now suffering from the fact that permits are revocable.
>
> A conference between representatives of the government and representatives of the power companies and of banking houses interested in financing power projects was held in Washington in February and March. The government opened the conference by proposing legislation of the character above indicated. The companies were unwilling to accept that unless they also got much more. The administration cannot therefore be held responsible for the fact that this legislation has not been secured.

The real question under discussion, then, is whether the government should grant very valuable privileges to the power companies upon conditions more favorable to the latter than are necessary to insure the development of water powers. The power companies are justly entitled to a rate of interest on their investment proportional to the initiative required and risk involved and one which will make the proposition attractive to capital, but why are they entitled to anything more?

It is stated in the paper that the reserves or national forests were created primarily for use and not for profit, but if there be profit involved in the administration of the reserves why should it not go to the government, representing the public rather than be handed over to a few corporations? The fact that the government has in the past practically given away for private exploitation by far the greater part of the natural resources of this country is not, it seems to me, an argument for giving away the small remnant the legal title to which still remains with the government.

If the granting of permits for 50 years, irrevocable except for breach of conditions, will result in the development of water powers with its many obvious concomitant benefits, what is to be gained by the granting of permits in perpetuity, except the enrichment of a few individuals? If there is any question as to whether 50 years is a sufficiently long period to induce the desired result, it would seem to be a reasonable method of ascertaining the facts for the government to offer to grant permits for this length of time and then, if permits are not applied for, the granting of permits for a longer period can be authorized. In any case the government should retain permanent control of all water power resources now in its hands, and issue permits for development under conditions fixed for a definite period, at the end of which time the government should be free to make new stipulations and adjust the conditions to the circumstances then existing.

Mr. Baum raises the question of monopoly, and while a monopoly of the water resources of this entire country may, as he says, be absurd, a monopoly of the water powers of a given locality is certainly possible and in many cases probable. Even where there is not a monopoly of the sources of power there may be a monopoly, through exclusive franchises or otherwise, of the power market practically available in a given district. Whatever the cause, the resident of a city in California confronted with a local power monopoly will derive no advantage from the fact that Niagara power, for example, is controlled by entirely independent financial interests.

In the paper it is stated that the profits of a national forest in California should not be used to maintain a reserve in Maine, but the proceeds from the sale of the public land included in the national forest would, if the reserve had not been created, have been turned into the national treasury, and not turned over to the state of California. Why should not the same course be followed with any profits which may arise from the administration of the reserve? Both before and after the creation of the reserve the land belonged and belongs to the nation.

It is true that settlers in the vicinity of a reserve should be given first consideration in the disposition of the products of the reserve, but, in general, water powers are not developed on a coöperative basis by the people who use the power, but by bondholders and stockholders at a distance. The price of power will always be determined by the cost of competitive power, or by the price at which, with the corresponding amount of business, the profits will be a maximum, not by the actual cost to the company of the power sold the consumer. The amount of the government charge affects the last item only, but the two determining factors are entirely independent of it.

Furthermore, while it is the policy of the government that settlers in the neighborhood of any one forest be preferred to people at a distance, so far as the right to use the land and resources of the forest is concerned, it is also its policy that,

> They should pay a fair price for all exclusive commercial privileges which they get. In other words, they should not be preferred to others as to price but should be preferred to others at the same price. This is the rule in the case of grazing permits, which are further restricted to prevent monopoly by large owners.

Whether it is "only fair that the government charge against the power privileges should be based on what the government furnishes", depends upon whether the cost or the value of what the government furnishes is meant. As an analogy the case of railroad ties is mentioned, and it is claimed that the value of these should be calculated on the yearly expense of maintenance and the number of ties the reserve can produce annually. As I understand the meaning of the word "value" it is the amount of money for which a thing can be sold. As a matter of fact, in disposing of any of the timber products of a reserve, it is the market value, determined by sale at public auction after advertisement, not the cost of maintaining the reserve, which fixes the price at which the timber is sold. An exception is made in the case of the small homesteader in the immediate vicinity of the reserve, who is given free certain forest privileges for personal and non-commercial use. Thus he can have without charge a small amount of timber, $20.00 stumpage annually, and is allowed to graze free six milk or work animals. When the timber is sold to a railroad or lumber company, the government receives the market price of that kind and grade of lumber. It would, it seems to me, be absurd for the government, representing the public, to sell timber from national forests to lumber companies for a nominal sum in order that the lumber companies might make an excessive profit in reselling it to the public.

While the charges of the government to the power companies should not be excessive and should not exceed a definite maximum set in advance, in order that the fixed charges on a development may be accurately foreseen, nevertheless I see no reason why the value of the power privilege rather than the cost of maintaining a given reserve should not be taken account of in determining the government charges, just as the market value of the timber is considered in fixing its price.

The value of the land for power purposes is approximately measured by the amount of power actually developed each year. It is also an inverse function of the cost of development per kilowatt and the distance from a market, but the obvious practical difficulties in the way of taking account of these and similar factors are such as to leave the amount of power developed as the only practicable basis upon which to evaluate the power privilege. Mr. Baum says very justly that the power man who discovers a better power development than another man should have the benefit of his enterprise, and it would therefore seem to be fair that the man who discovers a power having a low development cost per kilowatt, or one near a market, should pay a less percentage of his profits to the government, as he would with a uniform government charge per kilowatt, than a man who can only find a power which must be developed at high initial cost, or which is three hundred miles from a market.

As Mr. Pinchot says:

Any private land owner having a power site on his land would refuse to rent it for its value considered as a wood lot, but would insist on its power value as the basis of the annual rent. If his property were to be taken from him for power purposes by condemnation he would be entitled to its value for such purposes.

The principle involved has been affirmed by the Supreme Court of the United States. Why should the fact that the renter in the case we are considering happens to be the national government, make any difference? The power privilege is worth just as much to the power company whether it is secured from a private individual or from the government.

To summarize the difference between Mr. Baum's point of view and my own: he believes that water power development should be encouraged as much as possible; I believe that it should be encouraged only so much as is necessary to insure development. Beyond this the interests of the public, not those of the water power companies, should determine the government's policy.

J. A. Britton (by letter): I believe that the United States should grant to all bona fide hydroelectric corporations permanent rights-of-way and grants of government land without any tax whatever being made therefor, other than the cost of the land, fixed by the government on the same basis as valuation is fixed for homesteaders. Such rights, when granted, to become permanent only upon the expenditure of a sum of money representing four or five times the value of the land, and to provide therefor that upon cessation of use for a period of one year, except in case of unavoidable accident or destruction by elements of the improvements, the grant should revert to the United States.

The protection of a watershed should be a matter within the province of the United States, without imposing any tax upon the users of the land. The resultant benefits gained by the United States and the several states in which these patents would be used, and the taxes derived therefrom, are, in my opinion, sufficient to warrant the government in taking care of and protecting watersheds utilized, as such care and protection results as much to the benefit of the entire community through which the streams may flow, as it does to the company utilizing the water for power purposes. I am unalterably opposed to the levying of any tax by the state, or by the United States, where forest reserves are concerned, against enterprises of this character. To subject an investment of this kind to the whims of the legislature of any state and the Congress of the United States would be to invite confiscation of property, and would result in eventually paternalizing, and would, if neither of the above occurred, bankrupt any corporation, as it has no redress. Nor can it in California now, nor will it hereafter, be permitted to increase its rates, due to the trend of the present legislation in the matter of such close regulation of corporations. If any law is to be made, it should be a discriminatory one, choosing between the bona fide enterprises and those which are organized purely for the purpose of enriching the organizers.

I shall be very glad indeed to see a state or Coast convention held to discuss this subject. I believe it very vital to the welfare of those who have, in good faith, invested their money in water power propositions in California and other states.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

A STUDY OF MULTIOFFICE AUTOMATIC SWITCHBOARD TELEPHONE SYSTEMS

BY W. LEE CAMPBELL

This paper treats of three principal topics:

1. The enormous economic waste which the wire, cable, and conduit equipment of a telephone system involves.
2. A recapitulation and discussion of reasons which make this waste necessary or expedient in manually operated systems.
3. How this waste can and should be greatly reduced in systems employing automatic switchboards.

In other words, as most automatic switchboard plants have been installed in conformity with practices which emanated from experience with manual switchboard systems, the writer will discuss some of the reasons for these practices and endeavor to show that they can profitably be ignored in plans for automatic systems. To accomplish this he has made a study of the principal factors in the first cost of plants of both types, together with certain factors in their operating expenses. Since many telephone engineers have possibly not had an opportunity to study these factors, and would be much interested in a comparison of them, the writer has so arranged his data that they will be of use, not only in the discussion of his theme, but also in a determination of the measure of success which automatic switchboards have attained in furnishing the speedier, more uniform, and more economical service expected of them by the men who labored so hard and faithfully to develop them, and by the pioneers who had the courage to be their early purchasers and operators.

The first cost of a telephone plant using switchboards of either type may be divided into three principal items:

1. Cost of the apparatus (both central office and subscriber's station).

2. Cost of the central office buildings and furnishings.

3. Cost of the wire, cable, and conduit plant.

In the third item of the first cost—the wire, cable, and conduit plant—we find the largest factor of the three. The writer will not attempt, however, to give any average figures on the amount of this item. It is a variable quantity, depending in each system, not only upon the number of lines in the plant, but also upon the character of the soil, upon the average length of line as controlled by the density of population, by the form of the city, by the relative location of the business center or centers, and by obstructions, such as rivers, lakes, etc., and upon other similar conditions. Under almost any circumstances this part of the system will cost more than the two other parts combined; not infrequently it represents two-thirds of the entire first cost of the system.

It will, therefore, probably tax the credulity of engineers, whose experience has been in connection with electric power and lighting, when the writer states that in the average telephone system containing one central office only, nine-tenths of the cable and wire plant is idle—not in use for transmitting conversations, even at the peak of the load; and, too, that on the average during 24 hours' service, 98% of the wires are not in use. Yet such is the fact. Indeed, from observations made in a large number of automatic plants during the busiest hour, it was found that in offices of from 8,000 to 10,000 lines, handling a comparatively heavy traffic, the maximum number of conversations taking place at one time was equal to slightly less than 4% of the number of lines in service. As each conversation represents two lines, this would indicate a maximum of 8% of the lines engaged for conversation, operating and signaling at the peak of the load.

Excepting party-line service, which at best is but a partial remedy, there is only one method known to telephone engineers of to-day for materially reducing the great economic waste represented in the 90% of the costly cable, wire, and conduit equipment which is not in use even during the " rush hours ". This method is to divide up each plant so that instead of one large central office it will employ a number of smaller offices. Just how much saving can be effected in this way, depends upon the local conditions in each city; but it will be readily understood that if small central offices or stations should be distributed over a city at the centers of well selected districts, the telephones in each district being connected only to the local station, the subscribers' lines would be decidedly shorter and cheaper than when all run for many blocks to a large centrally located office. For interconnecting between the district stations, only trunk lines would be needed, and it is necessary to have only enough of these to handle the busy-hour traffic; that is, the trunk lines need to be but a small percentage of the number of wires which would be installed if each telephone should be directly connected to one large central office.

An arrangement resembling that just outlined is in use in large cities, where of necessity some division has been made in manual systems for the reason that it is physically impracticable to terminate all lines in one multiple switchboard; that is, within the reach of each operator. Many telephone engineers do not consider it good practice to connect over 10,000 lines to one manual board, and while several boards have been installed with an ultimate capacity of 18,000 lines, the parts are so small and comparatively delicate that it is probable that repairs and depreciation will be exceedingly large items.

The writer does not wish to convey the idea that in manual practice systems are not divided up to save wire and cable; for in a very large city covering a great area this must be done. For example, in Chicago there are 15 or 16 central offices averaging about 3000 lines each. But division of an office of less than 10,000 lines is generally regarded as undesirable and to be avoided wherever possible. It is, therefore, the general practice in smaller cities to carry all or the bulk of the business on one large board, smaller branch boards being installed under sufferance and only for urgent reasons. The writer hopes to demonstrate that while this antipathy toward dividing offices of 10,000 lines or less is reasonable in manual practice, it is not reasonable in automatic practice.

Taking up the study of the factors that govern the first cost of a common-battery system of either type, and considering them in the order in which they have been named, we find first, that the cost of the ordinary direct-line, flat-rate telephone at the subscriber's station is about the same ($7.25 each) in all sizes and conditions of modern common battery manual plants, and $12.50 each in automatic plants. The cost of a private branch switchboard at a subscriber's premises is not materially affected by the size, location, or type of the central office to which it is connected. This, therefore, will not be taken into consideration.

The cost of the central office equipment when all installed in one office depends upon the number of lines entering the office, and the number of connections demanded during the busy-hour of each day. No storage feature is possible in a telephone plant. The switchboard must be designed to take care of the peak of the load, no matter how exaggerated that peak may be.

For the purpose of this paper, the writer has drawn, as shown in Fig. 1, an arbitrary curve, *A*, from which will be taken all figures used on the number of calls made per line per day in

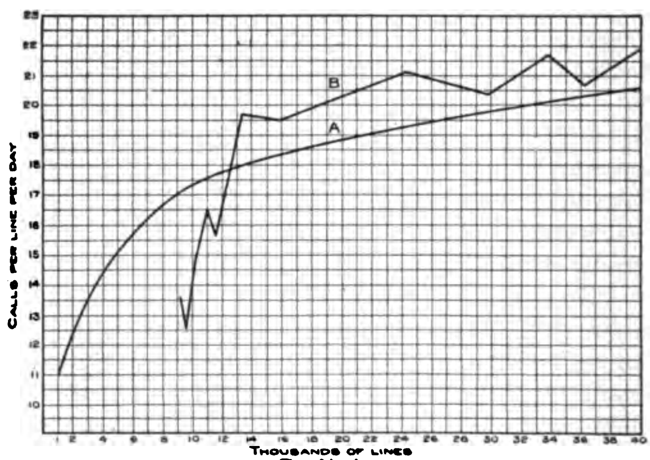

FIG. No. I

CURVE "A" SHOWS ARBITRARY NUMBER OF CALLS PER LINE PER DAY, USED IN MAKING COMPARISONS.

CURVE "B" SHOWS NUMBER OF CALLS PER LINE PER DAY IN CHICAGO DISTRICT FROM 1893 TO 1906.

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plants of different sizes. While this curve is not an unreasonable one, for flat-rate lines, it does not purport to be an exact average. Curve *B* in Fig. 1 shows the growth in the average number of lines in service and in the average number of calls per line per day in the "Chicago district" of the Chicago Telephone Company during the series of years, from 1893 to 1906. The writer supposes that the comparatively small traffic from 1893 to 1897 is largely due to the business depression then existing, and to the fact that the telephone had not then been sufficiently advertised to make it such an important factor, as it now is, in our business and social intercourse.

It will also be taken for granted that the number of calls made during the busy hour of each day is one-eighth of the total day's business. Experience shows that this is an average ratio. The average busy-hour's work of an operator in the small manual plants is about 225 flat-rate connections; in the

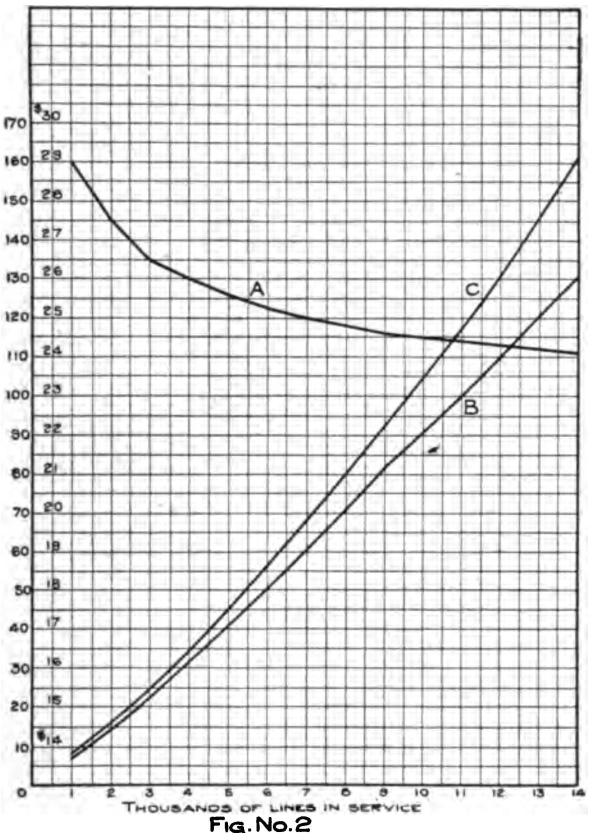

FIG. No. 2

CURVE "A" SHOWS AVERAGE NUMBER OF LINES IN SERVICE PER SUBSCRIBER OPERATORS POSITION.

CURVE "B" SHOWS NUMBER OF POSITIONS INCLUDING HOSPITAL AND LONG DISTANCE TRUNKING POSITIONS.

CURVE "C" SHOWS COST PER LINE OF ALL CENTRAL OFFICE EQUIPMENT EXCEPT LONG DISTANCE EQUIPMENT. (MANUAL OFFICES)

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large manual plants about 250 flat-rate connections when no calls are trunked to other offices. In explanation of this difference in connections handled, it might be well to say that discipline is usually better in the larger offices, and consequently the operators do more work than in the smaller ones.

With the foregoing points determined, curves *A* and *B*, Fig. 2, have been constructed. Curve *A* gives the number of flat-rate lines per operator's position, and *B* the number of operators' positions for manual switchboards equipped for

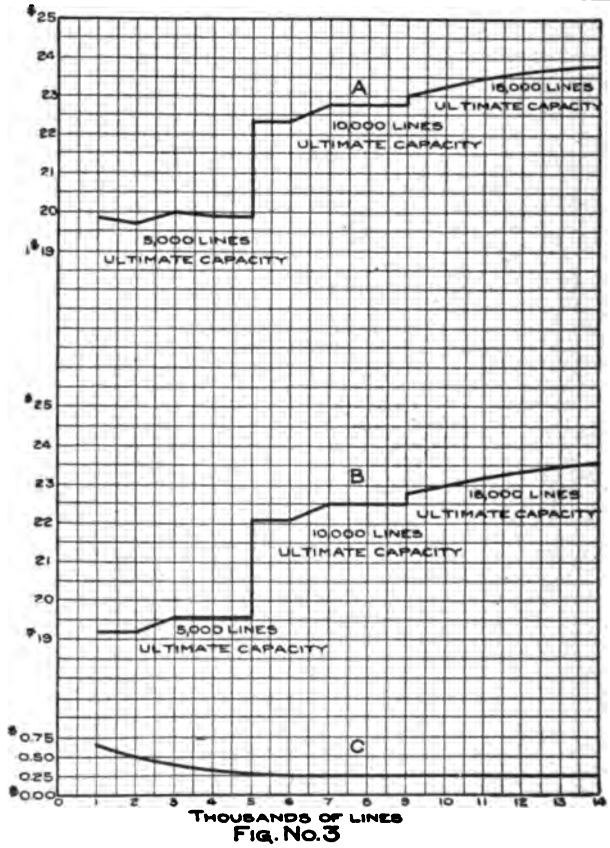

FIG. No. 3

COST OF CENTRAL OFFICE EQUIPMENT FOR AUTOMATIC OFFICES. NO TRUNKING

CURVE "A" SHOWS TOTAL COST PER LINE OF CENTRAL OFFICE EQUIPMENT INCLUDING DESKS

CURVE "B" SHOWS TOTAL COST PER LINE OF CENTRAL OFFICE EQUIPMENT EXCEPT DESKS THE COST OF WHICH IS SHOWN BY CURVE "C"

CURVE "C" SHOWS COST PER LINE OF WIRE CHIEFS, TROUBLE CLERKS, INFORMATION CLERKS AND OFFICE SUPERINTENDENTS DESKS.

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from 1,000 to 14,000 lines, and for handling the number of calls per line per day indicated by curve *A*, Fig. 1. Curve *C* was then constructed, using the figures represented by curves *A* and *B* and the average prices at which a number of modern, well constructed, manual central office equipments using common-battery multiple switchboards have been sold and installed.

Curve *A* in Fig. 3 gives the cost installed of automatic central office equipment for offices of from 1,000 to 14,000 lines, designed to handle the number of calls per line per day as given by curve *A*, Fig. 1. The cost of central office equipment of either type includes cost of terminal racks, power plant, wire chief's, information clerk's and trouble clerk's desks; in short, all apparatus except a long-distance board and its accessories. In making up the figures on the cost of automatic equipment, the number of trunking switches necessary per hundred lines for handling

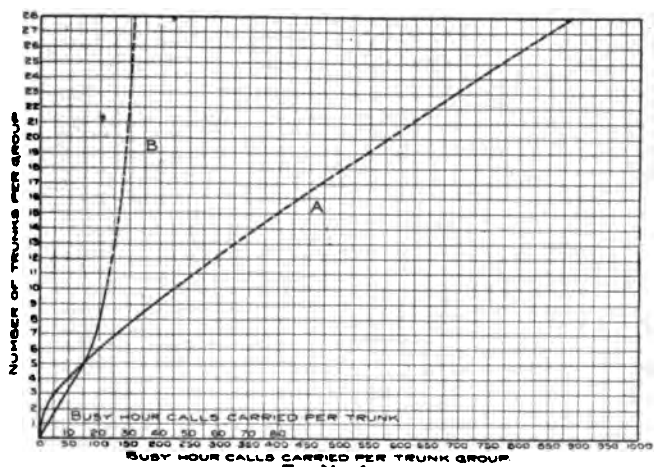

FIG. No. 4

CURVE "A" SHOWS RELATION BETWEEN NUMBER OF BUSY HOUR CALLS AND TRUNKS IN A GROUP FLAT RATE AUTOMATIC EXCHANGE CALLS AVERAGE HOLDING TIME 93 SECONDS

CURVE "B" SHOWS RELATION BETWEEN BUSY HOUR CALLS CARRIED PER TRUNK AND THE NUMBER OF TRUNKS IN THE GROUP AUTOMATIC SYSTEM. FLAT RATE CALLS

the busy-hour traffic was taken from curve *A*, Fig. 4. This curve, which is the result of thousands of observations made in automatic offices, follows the empirical formula:

$$\text{Trunks} = TC + 2.8\sqrt[3]{TC}$$

in which *T* represents the length in hours of the average connection and *C* represents the number of busy-hour calls.

For the benefit of those not familiar with automatic switchboards, the writer will state that each line terminates in what is generally called a line switch. These line switches are arranged and multiplied together in groups of 100 each. Connections between these groups are made by means of trunking switches called first selectors, second selectors, third selectors, and connectors. In a system having an ultimate capacity of 1000 lines, first selectors and connectors are the only trunking switches used. When the ultimate capacity is increased to 10,000 lines, second selectors are required also; and when the ultimate capacity is increased to 100,000 lines, third selectors are added. In a 100,000-line system, then, there is one first selector, one second selector, one third selector, and one connector for each trunk equipped.

A system with an ultimate capacity of 18,000 lines is made by installing a section of switchboard equipped for 8000 lines and arranged for an ultimate capacity of 10,000, and another section of switchboard equipped for the remaining 10,000 lines and using third-selector switches as if installed for an ultimate capacity of 100,000 lines. Such a combination does not involve any complications and makes the cost less than if the entire equipment were arranged for an ultimate capacity of 100,000 lines.

The cost of banks for ten selector switches of each type, and of ten connector switches per hundred lines, was included in all figures to allow margin for the practice, recently introduced into automatic plants, of moving selector and connector switches about from comparatively idle to busier sections in order to handle the busy-hour traffic with the least possible number of trunking switches. This practice is similar to that common in manual plants of apportioning the work among the operators' positions by means of an intermediate distributing frame.

In comparing these two first-cost curves (*C* in Fig. 2 and *A* in Fig. 3), it will be seen that the cost per line of manual equipment increases rapidly with the size of the office. This increase is principally due to the greater and greater number of multiple jacks which must be placed within each operator's reach, whereas, since the automatic is a trunking system, the cost per line is affected only by the slow growth in the number of trunks necessary to handle the busy-hour calls, and, at intervals, an increase in the ultimate capacity of the switchboard. The price of this equipment, therefore, rises more gradually and in the larger offices falls below that of the manual type.

For comparison only, the writer shows in curves *A* and *B*,

Fig. 5, the respective costs of manual and automatic central office equipment as given by curve *C*, Fig. 2, and *A*, Fig. 3, plus the cost of one telephone per line.

Taking up the second item of first cost for single office systems, the writer would direct attention to Fig. 6 in which curves *A*

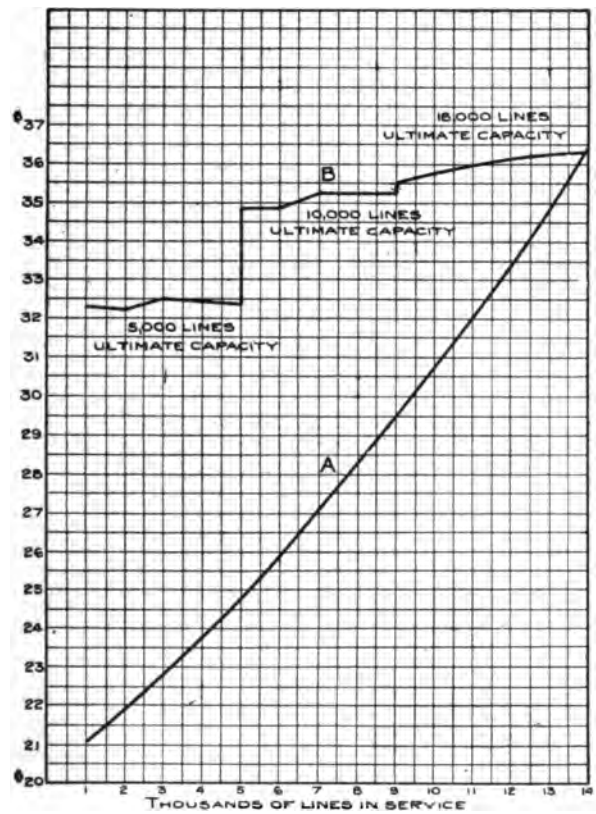

FIG. No. 5

COMPLETE COST OF CENTRAL OFFICE EQUIPMENT EXCEPT LONG DISTANCE BOARD PLUS COST OF ONE TELEPHONE PER LINE.
CURVE "A" IS FOR MANUAL OFFICES.
CURVE "B" IS FOR AUTOMATIC OFFICES.

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and *B* give the square feet of floor space required on the average for automatic and manual central office equipments respectively. Curve *C* gives the cubic feet of space required for automatic equipment, and curve *D* gives the cubic feet of space required for manual equipment. In this same figure, curve *E* for automatic equipment and curve *F* for manual equipment give the first cost of the necessary space in fire-proof buildings at an estimated rate of 19 cents per cubic foot for housing the automatic and manual equipments indicated. The cost of furnishings

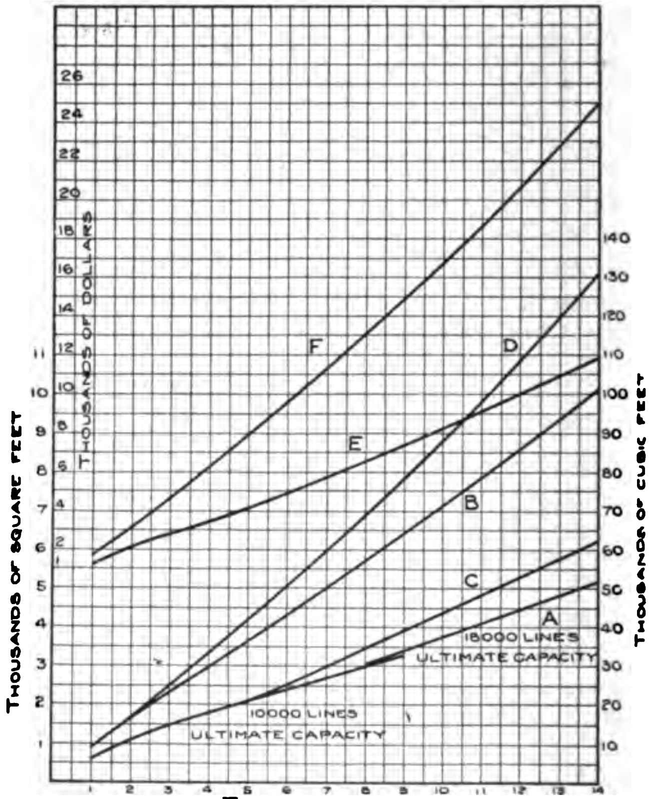

FIG. No. 6

CURVE A SHOWS SQUARE FEET OF FLOOR SPACE REQUIRED FOR AUTOMATIC CENTRAL OFFICE EQUIPMENT (NO TRUNKING)
CURVE "B" SHOWS FLOOR SPACE REQUIRED FOR MANUAL EQUIPMENT (NO TRUNKING)
CURVE "C" SHOWS CUBIC FEET OF SPACE REQUIRED FOR AUTOMATIC EQUIPMENT.
CURVE "D" SHOWS CUBIC FEET OF SPACE REQUIRED FOR MANUAL EQUIPMENT
CURVES "E & F" SHOW COST IN DOLLARS OF BUILDING SPACE REQUIRED FOR AUTOMATIC AND MANUAL EQUIPMENTS RESPECTIVELY FIRE PROOF BUILDINGS ESTIMATED COST 19 CENT PER CUBIC FOOT.

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and land, and cost of space used for executive offices, storage, etc., are not included, nor is the cost of space usually allowed for a growth of at least 20% or 25% in switchboards included. The figures do, however, include the cost of space for operators' rest rooms, hospital, dining room, kitchen, etc.

It will be noted that the cost of building space for automatic equipment is considerably less than that for manual equipment, and that for offices of over 5000 lines the automatic occupies about half the space required for the manual. No

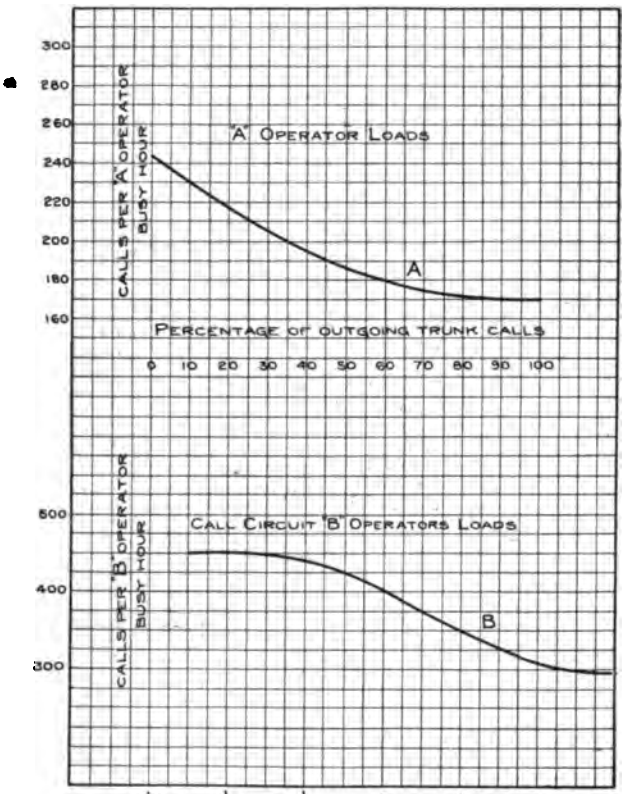

FIG. No. 7
OPERATOR'S LOADS

effort has been made to secure comparative figures on the cost of furnishings, but they are unquestionably more expensive in manual offices, since here recreation and rest rooms, restaurant, kitchen, etc., are commonly furnished and equipped for the use of the operators. In automatic offices the number of employees is comparatively small and the men are in the majority, consequently, it is not customary to make any elaborate provision for their comfort when off duty.

Having now shown what the average costs of the central office equipments and buildings would be in single office plants

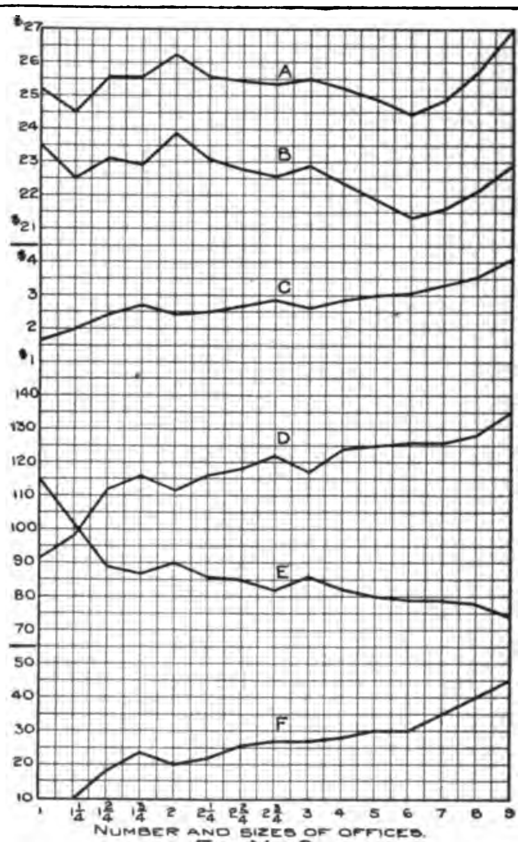

FIG. No. 8

STUDY OF 10,000 LINE SYSTEM WITH VARIOUS NUMBERS AND SIZES OF MANUAL OFFICES
ESTIMATED 173,500 CALLS PER DAY ESTIMATED 21,687 CALLS DURING BUSY HOUR
CURVE "A" SHOWS COMBINED COSTS OF CURVES "B" AND "C"
CURVE "B" SHOWS COST PER LINE OF CENTRAL OFFICE EQUIPMENT
CURVE "C" SHOWS COST PER LINE OF BUILDING SPACE REQUIRED FOR CENTRAL OFFICE EQUIPMENT FIRE-PROOF BUILDINGS ESTIMATED COST 19 CENTS PER CUBIC FOOT
CURVE "D" SHOWS NUMBER OF "A" OPERATORS POSITIONS REQUIRED AT ALL OFFICES.
CURVE "E" SHOWS THE AVERAGE NUMBER OF LINES SERVED BY EACH "A" OPERATOR'S POSITION
CURVE "F" SHOWS TOTAL NUMBER OF "B" OPERATOR'S POSITIONS.

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handling the traffic indicated by curve A, Fig. 1, it is next in order to see what effect dividing up a system so that it employs more than one office, has on these two items of first cost.

In manual systems an operator's daily quota of connections is reduced when part of the calls which she handles must be trunked to other offices. This effect of trunking on the operator's work is indicated by curve A, Fig. 7, which gives the number of flat-rate busy-hour connections which one of the largest manual operating companies has found that an average " A " operator will make with various percentages of trunked calls. It is, therefore, necessary in a multi-office manual system to install and to provide space for more " A " operators' positions, as well as to install and provide space for " B " operators' positions and to provide increased space for rest rooms, etc.

As an illustration, in Fig. 8, curves D, F, and E show respectively the number of " A " operators' positions, the number of " B " operators' positions, and the average number of lines per " A " operator's position for a hypothetical 10,000-line system with different numbers and sizes of offices. The numerals along the bottom of the figure which indicate the various numbers and sizes of offices, have the following significance:

1¼	represents	1 office of 8000 lines 1 office of 2000 lines
1½	"	1 office of 6700 lines 2 offices of 1650 lines each
1¾	"	1 office of 5725 lines 3 offices of 1425 lines each
2	"	2 offices of 5000 lines each
2¼	"	2 offices of 4450 lines each 1 office of 1100 lines
2½	"	2 offices of 4000 lines each 2 offices of 1000 lines each
2¾	represents	2 offices of 3650 lines each 3 offices of 900 lines each
3	"	3 offices of 3333 lines each
4	"	4 offices of 2500 lines each
5	"	5 offices of 2000 lines each
6	"	6 offices of 1667 lines each
7	"	7 offices of 1429 lines each
8	"	8 offices of 1250 lines each
9	"	9 offices of 1111 lines each

It will be noted that the number of " A " and the number of " B " operators' positions grows quite rapidly as the number of offices is increased, while the number of lines per " A " operator's position diminishes.

In working out these curves the percentage of outgoing trunk calls from any office was calculated by the formula; trunking% $= 100\,\frac{A-B}{A}$ multiplied by 0.75; where A is the total number of lines in the system, B equals the number of lines in the office under consideration and 0.75 is a factor which experience in-

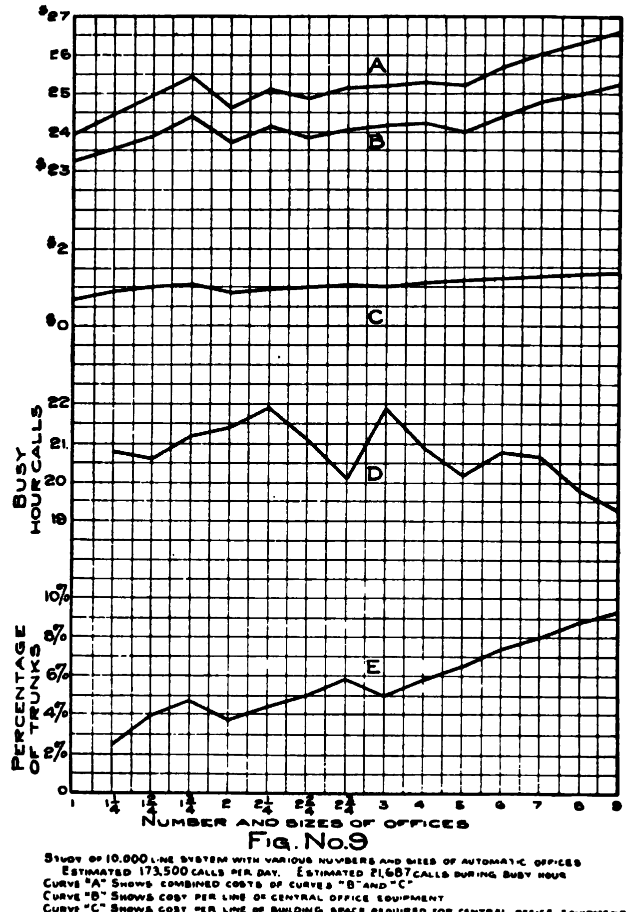

FIG. No. 9

Study of 10.000 line system with various numbers and sizes of automatic offices
Estimated 173,500 calls per day. Estimated 21,687 calls during busy hour
Curve "A" Shows combined costs of curves "B" and "C"
Curve "B" Shows cost per line of central office equipment
Curve "C" Shows cost per line of building space required for central office equipment
Curve "D" Shows the average number of busy hour calls carried per trunk line between offices.
Curve "E" Shows the ratio of the total number of trunk lines between all offices to the 10.000 subscriber's lines entering all the offices of the system.

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dicates will allow under average conditions for the community of interest between the subscribers in an office district. Of course, in a study of a particular locality this factor should, if possible, be accurately determined; it may be as small as 0.4 or as large as 1.5.

Curve *B*, Fig. 8, gives the approximate cost per line of the central office equipments installed as derived from the data used in curves *D*, *F*, and *E* previously mentioned. It will be noted that although more positions are necessary than in a single office, the cost of each position is reduced by a decrease in the line equipment and in the number of multiple jacks per position, so that there is not a great variation in the total switchboard cost. In the same Fig. 8, curve *C* shows the cost per line of the buildings for the various sizes and numbers of offices in the divided system. The cost of space required for executive offices, storage, etc., is not included in these figures, nor do they include the cost of land and furnishings. Curve *A* shows the combined cost per line of central office equipment and build-

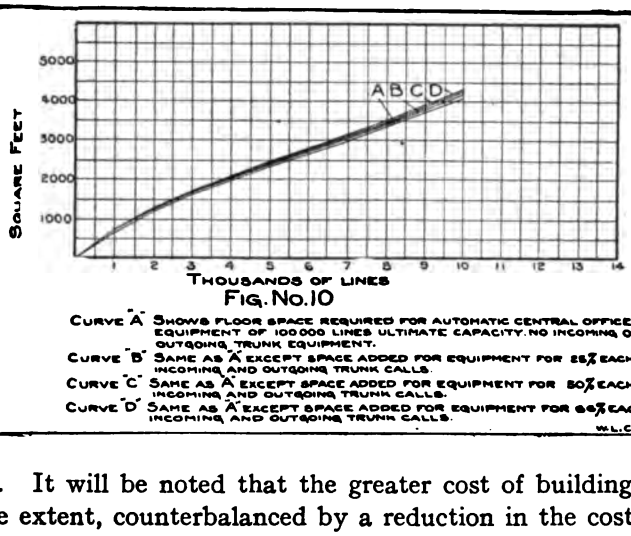

FIG. No. 10

CURVE "A" SHOWS FLOOR SPACE REQUIRED FOR AUTOMATIC CENTRAL OFFICE EQUIPMENT OF 100 000 LINES ULTIMATE CAPACITY. NO INCOMING OR OUTGOING TRUNK EQUIPMENT.
CURVE "B" SAME AS "A" EXCEPT SPACE ADDED FOR EQUIPMENT FOR 25% EACH OF INCOMING AND OUTGOING TRUNK CALLS.
CURVE "C" SAME AS "A" EXCEPT SPACE ADDED FOR EQUIPMENT FOR 50% EACH OF INCOMING AND OUTGOING TRUNK CALLS.
CURVE "D" SAME AS "A" EXCEPT SPACE ADDED FOR EQUIPMENT FOR 66% EACH OF INCOMING AND OUTGOING TRUNK CALLS.

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ings. It will be noted that the greater cost of buildings is, to some extent, counterbalanced by a reduction in the cost of the equipment. The small increase would in any event be of little moment in comparison with the saving in the cost of the wire, cable, and conduit plant, which might be secured by plant division. It would, therefore, appear that we must look further for the cause of the objections to multi-office manual systems.

Before discussing operating expenses, however, let us see what effect plant division has on the first cost of automatic central office apparatus and buildings. To illustrate the effect, the curves in Fig. 9 have been worked out, using the same 10,000-line system and the same numbers and sizes of offices employed in Fig. 8 for the manual system. The cost, installed, of central office equipment is somewhat increased by division, as will be noted by reference to curve *B*. The central office space required is also greater, as shown by curve *C*, Fig. 9, and by curves *A*, *B*, *C*, and *D*, Fig. 10. The slow increase in the combined cost of equipment and building as more offices are added is shown by

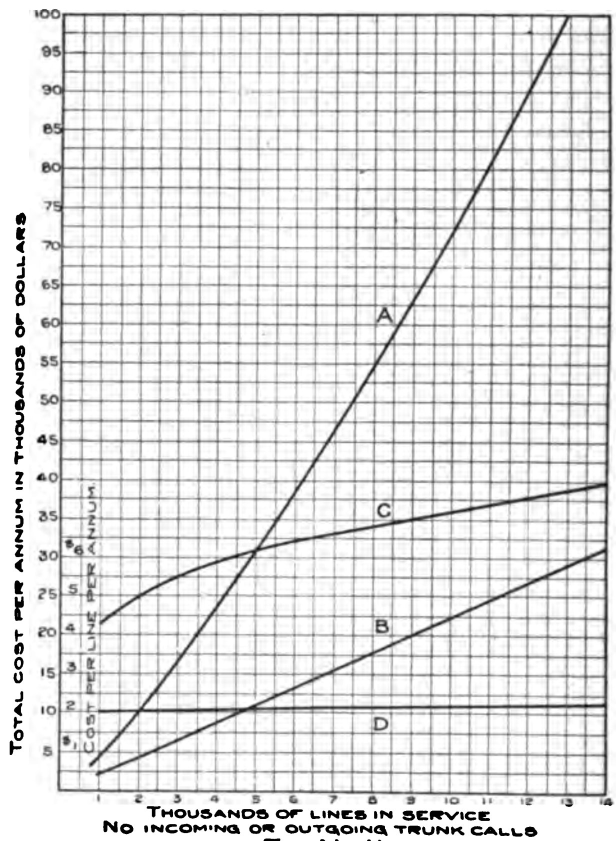

FIG. No. 11

COST OF LABOR FOR OPERATING, REPAIRING AND MAINTAINING ALL CENTRAL OFFICE EQUIPMENT EXCEPT "LONG DISTANCE BOARD" INCLUDES ALSO WIRE CHIEF AND ASSISTANTS, TROUBLE AND INFORMATION CLERKS

CURVE "A" GIVES TOTAL PER ANNUM FOR MANUAL EQUIPMENT
CURVE "B" GIVES TOTAL PER ANNUM FOR AUTOMATIC EQUIPMENT
CURVE "C" GIVES COST PER LINE PER ANNUM FOR MANUAL OFFICES
CURVE "D" GIVES COST PER LINE PER ANNUM FOR AUTOMATIC OFFICES

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curve *A*, Fig. 9. The increases are of small import in comparison with the saving in the underground and aerial construction secured by using a larger number of offices.

Taking up the subject of operating expenses, the writer would direct attention first to curves *A* and *C*, Fig. 11, which show average annual operating and maintenance labor cost for manual central offices of from 1000 to 14,000 lines, doing no trunking and handling the number of calls per line per day indicated by curve *A*, Fig. 1. Curves *B* and *D*, Fig. 11, show respectively the total annual cost and the annual cost per line of all central office labor for automatic offices of from 1000 to 14,000 lines. These figures are averages of the labor costs obtained from a considerable number of automatic switchboard operating companies.

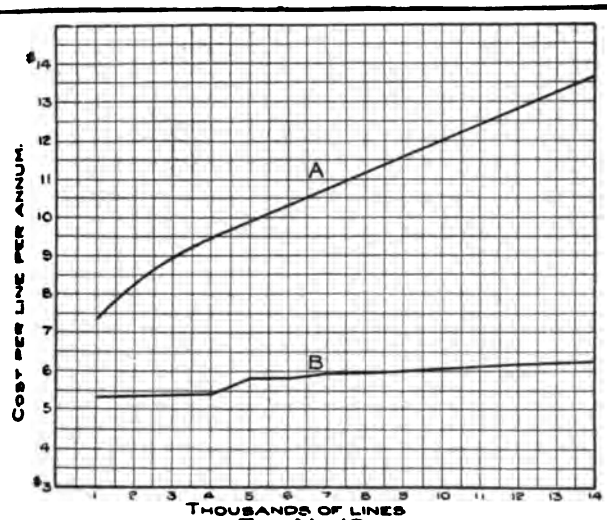

Fig. No. 12

Curve "A" Shows cost per line per annum for operating manual central office as shown by curve "C" Fig. 11 plus cost of power, lighting and interest, depreciation, taxes and insurance on central office equipment and on central office building

Curve "B" Same as "A" but for Automatic equipment (See curve "D" Fig. 11)

The writer would next direct attention to curves *A* and *B*, Fig. 12, which give the central office labor expense as shown in Fig. 11, plus the cost per line per annum of certain central office equipment and central office building charges that are materially affected by plant division. Curve *A* is for manual offices of from 1000 to 14,000 lines, no trunking, and curve *B* gives similar data for automatic offices. These figures include insurance, taxes, interest and depreciation on central office equipment and buildings, renewals for central office equipment, and the cost of lighting and power.

Insurance of the central office equipment in fire-proof buildings is taken at 1% per annum. Although several companies operating automatic apparatus have informed the writer that they secured a lower rate than that which they could get on manual equipment, it does not appear that the rating authorities have made any general rule which would assure a reduction. Since, however, much of the damage done to switchboards by fire is caused by blazes originating within the apparatus itself, and since the insurance companies exempt themselves from losses caused by such blazes, it would seem that fire losses would be smaller with automatic equipment than with manual. Manual switchboards are largely built of inflammable material and are incased in wooden cabinets. Also, if a blaze should start in one end of a manual board, there is little in the construction of the board to prevent it from sweeping through the entire length. Automatic switchboards are divided up into small separated sections so that a blaze in one would have very little opportunity to leap across to another. The apparatus itself is made up almost entirely of metal.

Taxes on both types of equipment are figured at the rate of 1.5% per annum; interest is figured at 6% per annum for both.

Depreciation on manual central office equipment is figured on an average life of 10 years. Of course, many parts of the switchboard must be replaced in less time: for example, cords in an average time of 1.5 years, plugs in 2 years, keyboard lamps 3 years, answering jacks 5 years, etc. These, however, are believed to be covered by including a 2% charge for maintenance materials and renewals. Depreciation on automatic equipment is calculated on a life of 12 years. Although no automatic plants, to the best of the writer's knowledge, have been in continuous service for this length of time, he has found that plants which have been in operation for 7 or 8 years show very little wear. While some such plants have been replaced by new ones, it has been because it was believed that better service and decreased operating costs, made possible by the new and improved equipment obtainable at the time the change was made, would pay for making it before the life of the original plant was exhausted. As an example, showing the effect of wear and tear on an automatic switchboard, there is in Fall River, Mass., an automatic plant which has been in operation for 7 years; at this plant the only appreciable wear is on the shaft wipers of the busier trunking switches. While these wipers could be renewed at a very modest expense, they will apparently last for some years yet. The wear on the equipment, which is individual to each subscriber's line, is hardly noticeable. In fact, an automatic switchboard has never been known to wear out, while manual switchboards are really worn out by the continued use of the parts by the operators. As the writer has already stated, such manual switchboard parts as cords, keyboard lamps, answering jacks, trunk jacks, etc., will need to be replaced at intervals during the life of the board. It is also found that the keyboards and plug shelves made of wood and sole leather become so worn from the continual contact of the operators fingers and the rubbing of the cords, and so battered by the constant pounding of the plugs, that they must be replaced in 6 or 7 years on a very busy board. In 10 years, or sometimes even less, the keys, multiple jacks, multiple cables, etc., are generally in such condition that it becomes necessary to replace the entire switchboard, regardless of whether it has become obsolete or not.

Ten to fifteen years ago telephone apparatus was being developed so very rapidly that the life of a board was not more than 5 or 6 years. At the end of that time the board would be so out-of-date that competition or a proper regard for service or for operating expenses would usually compel its replacement by a more modern one. That time ended in manual practice with the perfection and introduction of the common-battery multiple board. No radical improvements have since been made. Automatic switchboards have also reached a somewhat similar plane of development. For illustration, in the Fall River system installed in 1901, a subscriber makes a call by means of a dial, and secures service very similar to that in the most modern plant. Looking at the automatic switchboard itself, we find the so-called grouping system, the automatic selection of trunks, push-button ringing, and other essential features of the latest equipment. It is true that great improvements have been made in automatic equipment in very recent years, such as the introduction of common-battery service, party lines, line or individual switches, improved methods of manufacture, installation, etc., but these are all points which appeal to the manufacturer or to the operating company, while improvements in the general appearance of the telephones are about the only ones made in the last 7 or 8 years which are of much interest to the telephone users. Therefore, considering service only, and viewing the matter from the standpoint of the telephone subscriber, the writer believes it reasonable to conclude that there is little probability, in the near future, of a manual switchboard being rendered obsolete by a more improved manual board or of an automatic switchboard being put out of the arena by an automatic switchboard giving better service. He, therefore, has taken the life of a manual switchboard at the full amount that a consideration of wear and tear only will permit; and, in order to be perfectly conservative, has placed the life of an automatic board at but 2 years longer although there is no reason to suppose that it would not still be good for a number of years of service at the end of that time. The amount which must be set aside annually at 6% compound interest to equal 100% in 12 years is 6% of first cost. Therefore, this percentage is used in calculating depreciation on automatic central office equipment, while for manual equipment the depreciation charge is taken at 7.5%, which is the amount which must be set aside annually at 6% compound interest to equal first cost in 10 years.

Looking into the matter of maintenance material or renewals for automatic central office equipment, the writer has found from an investigation of a number of automatic plants that the renewals for the switchboard proper amount on the average to 0.2% per annum on the first cost of the central office equipment. The power plant, main distributing frame, and other parts of the central office equipment, increase the renewals item, however, and in order to cover everything it has been taken at 0.5% for automatic offices.

The cost of power per originating call handled is about twice as much for automatic switchboards as for most of the manual switchboards used by the "independent companies". The amount of current consumed is almost the same, 0.006 of an ampere-hour. Automatic plants generally use a battery of 46 volts, about twice the voltage of the usual manual battery, although in large plants where the lines are long, 40-volt batteries are sometimes employed in manual practice. The manual switchboards generally used by the Bell companies require considerably more current than those used by the independent companies. The amounts used by the independent boards have been taken in working out the curves in this paper. Taking the cost of power, transformed and delivered at the switchboards, at 15 cts. per kilowatt-hour gives a cost of $0.0216 per thousand local calls for manual offices and of \$0.0432 per thousand local calls for automatic offices. The additional cost per thousand incoming trunk calls received at a manual office would be \$0.0144. For automatic offices the additional cost for incoming trunk calls would be \$0.004 per thousand, assuming that the number of calls trunked out from an office equals the number incoming.

The cost of lighting automatic central office equipment has been taken at \$4.00 per thousand lines per month; and for manual offices the cost of lighting the operators' positions, the switchboard rooms, operators' retiring rooms, terminal room, desks, etc., has been taken at \$2.00 per switchboard position per month.

The annual charges on the central office buildings have been taken at the same rates for the two systems; that is, insurance on fire-proof central office buildings has been figured at 0.5% per annum, interest at 6%, taxes at 1%, and depreciation and repairs at 2% per annum.

In order to illustrate the effect on the annual expenses, just discussed at length, caused by dividing a system up so that it employs a number of offices instead of one, the writer has constructed the curves in Fig. 13, which show what the expenses would be for the different numbers and sizes of offices in the hypothetical 10,000-line system used in Figs. 8 and 9. Referring to curve *A* in Fig. 13, it will be noted that the annual cost of central office labor for the nine-office arrangement of the manual system is 80% greater than for the single office arrangement.

It might be stated just here that the item of operators' hire is one which yearly grows to greater magnitude. One very large telephone operating company instructs its engineers engaged in development studies to estimate on operators salaries being at least 15% higher 15 years hence.

Curve *B*, Fig. 13, shows that the increase in the cost of labor plus the annual charges on equipment and buildings, weighs heavily against the division of manual systems. In fact, experience shows that where the ultimate number of subscribers that may be expected in an office district within fifteen years does not exceed the capacity of a single multiple board (about 10,000 lines) and there is no concentrated group of subscribers at a considerable distance from the best location for a single office, it is generally found that a one office system will be the most economical when manual equipment is used.

There are conditions under which it is profitable to divide manual 10,000 line plants; that is, there are conditions under which the saving in the annual charges on cable, wire and conduit, will more than offset the increase in central office expenses,

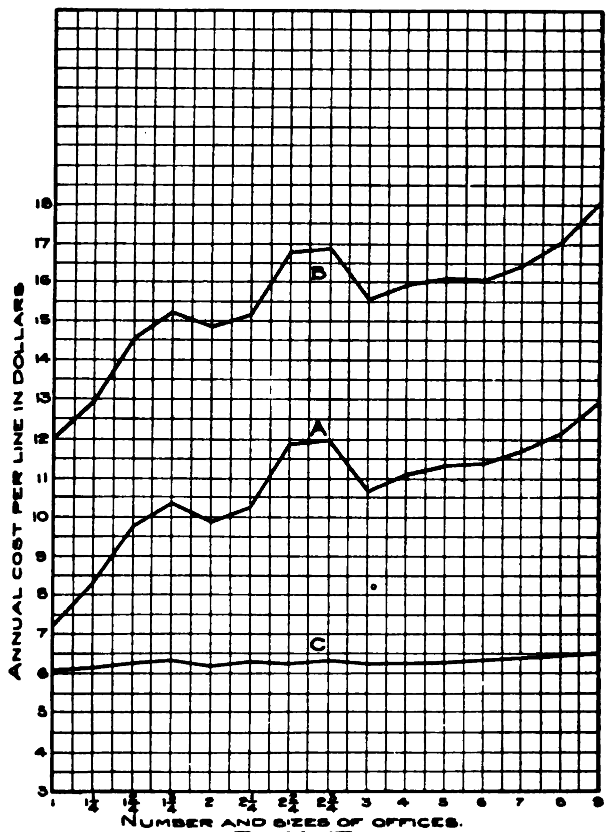

FIG. No. 13

CURVE "A" GIVES ANNUAL EXPENSE PER LINE OF ALL CENTRAL OFFICE LABOR FOR A 10,000 LINE MANUAL SYSTEM WITH DIFFERENT NUMBERS AND SIZES OF OFFICES THE SAME AS USED IN FIG. 8.

CURVE "B" SHOWS LABOR COST AS GIVEN BY CURVE "A" PLUS INTEREST, TAXES, DEPRECIATION MAINTENANCE AND INSURANCE ON MANUAL CENTRAL OFFICE EQUIPMENT AND ON CENTRAL OFFICE BUILDINGS, ALSO PLUS COST OF LIGHTING AND POWER.

CURVE "C" SHOWS FOR A 10,000 LINE AUTOMATIC SYSTEM (SEE FIG. 9) THE SAME ITEMS AS THOSE GIVEN IN CURVE "B" FOR A LIKE MANUAL SYSTEM.

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if division is not carried too far. It is, of course, necessary to make a thorough engineering study of each apparently suitable location for a branch office, to determine whether or not any real economy would result; but since the annual charges on subscribers' lines less than two miles long using No. 22 gauge cable conductors average about $2.50 per mile, it will be seen that the saving in length of line will be less than the corresponding increase per line per annum in central office expenses (indicated by curve " B " in Fig. 13) except where the lines are comparatively long. Roughly speaking, an economical arrangement of the average divided manual system will include offices not much less than two miles apart.

Curve *C* in Fig, 13 shows that division of automatic systems may be profitably carried much further on account of the slow

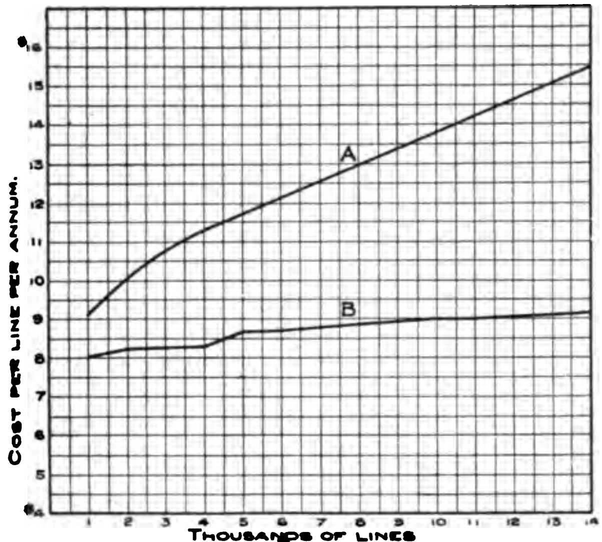

FIG. No. 14

CURVE "A" SHOWS COST PER LINE PER ANNUM OF MANUAL CENTRAL OFFICE AND CENTRAL OFFICE BUILDING EXPENSES (SEE CURVE "A" FIG. 12) PLUS INTEREST, DEPRECIATION AND TAXES ON ONE TELEPHONE PER LINE AND PLUS COST OF CLEARING LINE AND TELEPHONE TROUBLE

CURVE "B" SHOWS COST PER LINE PER ANNUM OF AUTOMATIC CENTRAL OFFICE AND CENTRAL OFFICE BUILDING EXPENSES AS GIVEN BY CURVE "B" FIG. 12 PLUS INTEREST DEPRECIATION, TAXES AND CALLING DEVICE REPAIRS ON ONE TELEPHONE PER LINE AND PLUS COST OF CLEARING LINE AND TELEPHONE TROUBLE.

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increase in central office expenses resulting from adding to the number of offices.

The writer hopes that he will be pardoned if, before leaving the subject of operating expenses, he pauses to call attention to curves *A* and *B*, Fig. 14, which include the office expenses as given by curves *A* and *B*, Fig. 12, plus the annual cost per line of clearing line and telephone trouble, and plus the annual charges for interest, depreciation, and taxes on one telephone per line.

In calculating depreciation, the life of the telephones for both systems has been taken to be 10 years. It might appear unreasonable at first thought to believe that the more complicated automatic telephone has as long a life as the simpler manual instrument, but experience shows that the parts of a telephone which depreciate most rapidly are those which are handled by the user, knocked and rubbed against by passers-by and mischievous persons; also that the parts which must be kept highly finished, because they are exposed to view, are most quickly affected not only by human contact but by sunshine, dampness, etc. Consequently, since very little more of an automatic telephone than of a manual telephone is exposed, and since the calling device, which represents about 40% of the value of the instrument, is locked inside the case, where it is subject only to wear and tear of legitimate service, which it will successfully withstand for at least 15 years, the writer has concluded that automatic telephones could reasonably be considered to be longer lived on the average than manual telephones. He has, however, as already stated, placed the two on the same basis.

The cost of material for repairs and renewals on automatic telephones is a little greater than for the manual. It was found by a thorough investigation that the cost of new parts peculiar to the automatic telephones amounts to 0.14% per annum. This difference has, therefore, been noted in comparing maintenance costs of the two systems in Fig. 14.

The cost of labor for keeping telephones in order is included in the curves in Fig. 14 and for automatic telephones is also shown separately in Fig. 15. No insurance on the telephones is included.

Returning to the subject of plant division and its results, there is still another point to be considered, namely, the effect of plant division on service. An investigation of this reveals what is a very serious objection to a multi-office manual system; because slower service, more mistakes by the operators, and, what is most aggravating to a telephone subscriber, more premature disconnections during conversation, are the inevitable results of having connections handled by two operators instead of by one. The good will of the telephone user is something which cannot be lightly considered in these days of keen telephonic competition. Unpopular service is not only a serious handicap in a contest with a rival company; but it also retards growth, invites higher taxes and hostile legislation, and often results in a general clamor for the regulation and reduction of rates. On the other hand, a record of giving service which meets with the general approval of its subscribers is an asset of inestimable value to any telephone operating company, and, in fact, is the best reason for the company's existence. We find, therefore, telephone managers, who are chiefly concerned in pleasing the public, pretty solidly arrayed against having manual systems split up, except where the number of stations is so great or the area covered by the system so large that rates would be excessive if one central office only were used. In fact, "no divided systems," was one of the battle cries of the leaders of the inde-

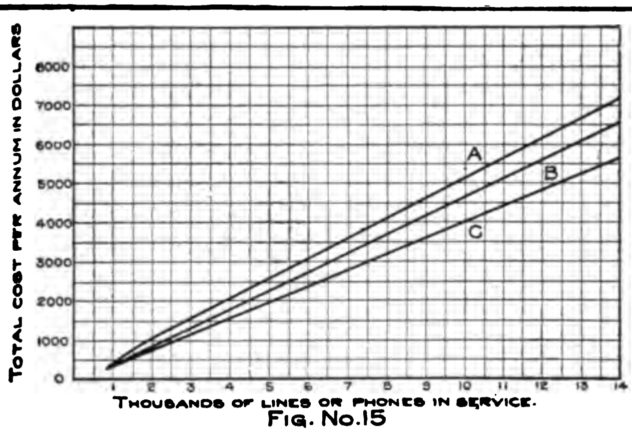

FIG. No. 15

COST OF LABOR FOR CLEARING TROUBLE IN AND MAINTAINING PHONES AND OF CLEARING LINE TROUBLES.

CURVE "A" SHOWS LABOR COST FOR CLEARING AUTOMATIC PHONE TROUBLE WITH RELATION TO TOTAL NUMBER OF PHONES IN SERVICE. (AUTO C.B. SYSTEM)

CURVE "B" SHOWS LABOR COST OF CLEARING LINE TROUBLE WITH RELATION TO THE NUMBER OF LINES IN SERVICE. (AUTOMATIC SYSTEM.)

CURVE "C" SHOWS LABOR COST OF CLEARING LINE TROUBLE WITH RELATION TO THE NUMBER OF PHONES IN SERVICE. (AUTOMATIC SYSTEMS)

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pendent telephone movement which has spread over the country so rapidly and so widely that its present magnitude baffles conception.

Increasing the number of offices in an automatic system does not appreciably affect the service. All calls are trunked anyhow, whether one office is used or many. Therefore, splitting up such a system does not add to the amount of trunking or in any way affect the speed and uniformity of service. The subscriber is not required to change his method of calling or to make more turns of his dial. No more automatic switches are necessary and a connection does not include any more switches in a divided system than in a single office plant. When the writer states that the service of a multi-office automatic system is on a par with that of a single office automatic system, he believes that he gives it the highest endorsement possible in the present state of the telephone art; for the companies operating automatic switchboards have demonstrated beyond question that they can give satisfactory service and furnish any special attention to which patrons of the girl-operated systems have been accustomed. Indeed, telephone users, who have had experience with both, almost universally prefer the automatic service to the manual. This fact is not only attested by all who have made an investigation, but has been publicly affirmed repeatedly in the reports of prominent public servants and engineers. For example, attention might be directed to the address delivered by Mr. Kempster B. Miller, before the International Electrical Congress at St. Louis, in 1904.

Not only has the writer not discovered any reasons which weigh materially against division of automatic systems, but he finds that the saving in the investment in cable, wire, and conduit would be even greater than in a manual system. First, because division may, as clearly shown, be carried much further without seriously affecting central office expenses, and secondly, because the number of trunk lines required for handling traffic between automatic offices is less than between similar manual offices. In other words, an automatic trunk will carry, on the average, more busy-hour calls than a manual trunk.

Curve *A*, Fig. 16, shows the call-carrying capacities which one of the largest manual telephone companies instructs its engineers to use in arriving at the number of trunks needed between proposed offices. As a rule, a manual trunk should not be expected to handle over 15 to 18 calls during the busy-hour even between rather large, well-managed offices; between small offices from 10 to 12 is all that can safely be depended upon. Reference, however, to curves *A* and B, Fig. 4, shows that between automatic offices a considerably higher trunk-carrying capacity is experienced. The largest number of trunks per group almost universally used in automatic systems is 10. Therefore, the curves in Fig. 4 are dotted above the line corresponding to 10 circuits per group. With groups of this size a minimum carrying capacity of 22.5 busy-hour calls per trunk is secured. This is a decided increase over the carrying capacity of manual trunks even where the latter are installed in groups of the greatest efficiency; that is, groups of about 73 circuits each. It would rarely, if ever, be possible to obtain such a large group if a manual plant were so divided that all offices were comparatively small, but in almost any multi-office system the majority of the trunks between offices can readily be placed in small groups of 10 trunks each. Consequently, in an

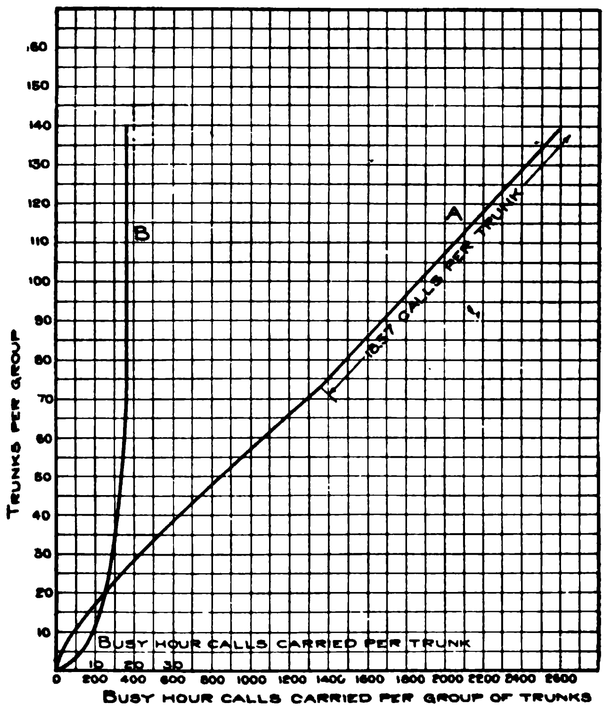

FIG. No. 16

CURVE A SHOWS RELATION BETWEEN NUMBER OF FLAT RATE CALLS AND CIRCUITS IN THE GROUP. LOCAL "B" TRUNKS AVERAGE HOLDING TIME 2 MINUTES MANUAL SYSTEM

CURVE "B" SHOWS RELATION BETWEEN THE NUMBER OF CIRCUITS PER GROUP AND THE NUMBER OF BUSY HOUR CALLS CARRIED PER CIRCUIT

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automatic multi-office system maximum efficiency is secured on nearly all of the trunks. This is illustrated by curve *D*, Fig. 9, which gives the average minimum carrying capacity per trunk for each of the different arrangements of the hypothetical 10,000-line system. The average minimum number of busy-hour calls carried per trunk is, according to the curve, about 20.75, and the lowest figure is 19.3 for the nine office arrangement. Supposing, for the moment, that it be practicable to use this nine-office arrangement in a 10,000-line manual system, the average number of busy-hour calls carried per trunk would be about 12.

The small number of trunks that will carry the traffic between automatic offices even in a thoroughly divided system is illustrated by curve *E*, Fig. 9, which shows the ratio on a percentage basis between the number of trunks and the number of subscribers' lines. With the largest number of offices considered this percentage is but 9.3.

One reason for the increased efficiency of automatic trunks is found in the shorter length of time per connection. In manual practice it has been found that each trunk is occupied on the average at least two minutes per connection, whereas automatic experience proves that during the busy-hour a trunk is not occupied over 83 seconds per average connection. A subscriber to automatic service answers his telephone quicker and generally does not hold the line so long for conversation as does a manual subscriber; also, the disconnection is made much quicker in the automatic system. This feature of the quicker disconnection is especially helpful during the busy hours when manual operators are most likely to be rushed and consequently slow about pulling down connections. The interval of time that elapses between release of a trunk by one automatic selector and seizure of it by another need be, and often is, but a fraction of a second. This, too, helps to increase the carrying capacity of the trunks.

The writer was much interested while studying the efficiency of the trunks of the two systems to note the difference between the number of connections existing at the busiest moment of the day in manual and automatic offices. For example, in the central office of a busy manufacturing city in Ohio a count was taken every day for a week in January of one year to ascertain the maximum number of connections "up" in the various operators' positions at intervals during the busy hours of each day. The results for the busiest day are shown in curve *A*, Fig. 17. A few months after these observations were made the equipment of this office was changed to the automatic type. In the following January, one year after the original data were secured, counts were made every day for one week of the number of connections "up" during the busy hours in the automatic switchboard. The results for the busiest day are shown in curve *B*, Fig. 17. It will be noted that the maximum percentage of connections counted at one time on the manual was 7 while on the automatic it was but 4.36. Similar observations were made on a number of automatic plants, and, as already stated earlier in this paper, it was found that in busy automatic offices of 8000 or 10,000 lines, the maximum number of connections counted at the busiest moment did not exceed 4%. In small offices of less than 1000 lines where erratic fluctuations of the traffic are more noticeable the maximum ran up to 4.7% in some instances.

A still higher trunk efficiency could often be secured in automatic systems if the trunk groups could be made larger than 10

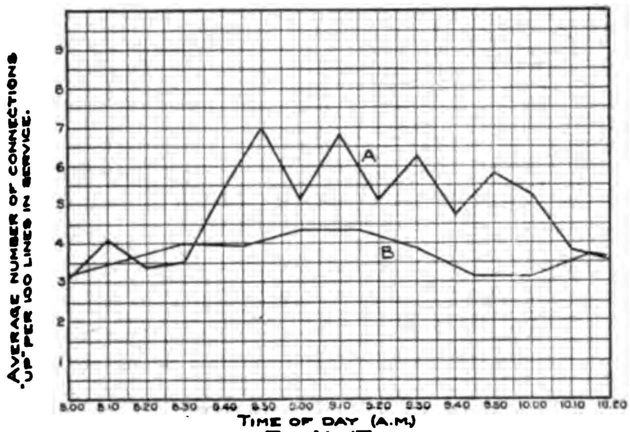

FIG. No. 17

CURVE "A" IS FOR A MANUAL OFFICE OF 2000 WORKING LINES AND 3002 TELEPHONES
CURVE "B" IS FOR THE SAME OFFICE WITH 2230 WORKING LINES AND 3112 TELEPHONES ONE YEAR LATER AND AFTER AUTOMATIC EQUIPMENT HAD BEEN INSTALLED.

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lines each without impairing the speed at which idle trunks are selected. This is shown by the dotted portions of curves *A* and *B*, Fig. 4, which give the carrying capacity per group and per circuit for groups up to 28 circuits each. On account of the fact that in an automatic system where the number of offices is comparatively large, and each office is comparatively small, the trunks are generally divided into a large number of small groups, and it is doubtful if there would be anything gained by making the maximum size of a group of trunks between offices greater than 20 circuits. Indeed in such a system many of the groups would contain considerably less than 20 circuits each.

The manufacturers of automatic apparatus have recognized the possibilities of larger groups and are now testing equipment designed to enable them to put more lines in each. Since such equipment has not come into general use, however, it will not be considered further in this paper.

In endeavoring to form some conception of the methods used for introducing trunking of calls on a large scale between automatic offices, it is well to understand the difference between two general types of office that are being used for this purpose.

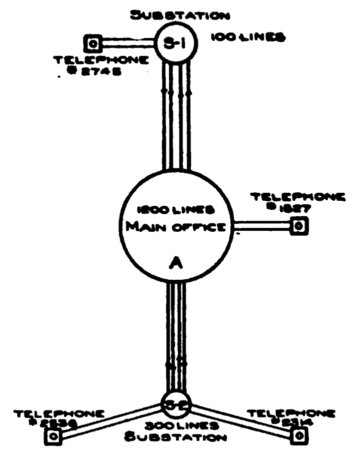


FIG. No. 18
NUMBERS IN "A" OFFICE RUN FROM 1000 TO 2199
NUMBERS IN "S-2" OFFICE RUN FROM 2300 TO 2599
NUMBERS IN "S-1" OFFICE RUN FROM 2700 TO 2799

One is known as a " sub-station " or " district " office and the other as a " branch " office. The difference lies in that a sub-station contains line switches and connector switches but no apparatus for making local connections; that is, every originating call is trunked to a distant larger office containing the selector switches, whereas a branch office contains switches of all classes and completes within itself all local connections demanded. It will readily be seen, therefore, that a sub-station requires more outgoing and incoming trunks than a branch office.

For an illustration of a system using sub-stations attention is directed to Fig. 18, in which *A* represents a " main " office containing the equipment for 1200 lines. " A " contains also the first selector and second selector switches used by two substations *S*-1 and *S*-2. *S*-1 is represented as containing line switches and connector switches for 100 lines and *S*-2 is supposed to contain line switches and connector switches for 300 lines.

Calls would be handled as follows: suppose for example, a subscriber at telephone No. 2314, which is connected to substation *S*-2, to be calling No. 1527 connected to the main office *A*. The impulses sent over the circuit through the calling device of telephone No. 2314, would first operate a line switch at *S*-2, which would instantly extend the connection over an idle trunk to a first selector switch at *A*. This first selector switch would be operated by the impulses corresponding to the first digit " 1 " of the desired number, and, would extend the connection to a second selector, also located at *A*. This second selector would be operated by the impulses corresponding to the second digit 5 of the desired number and would extend the circuit to a connector switch in the " 1500 group " at *A*. This connector switch would be operated by the impulses corresponding to the last two digits 2 and 7 of the desired number and would complete the connection to line and telephone No. 1527. Suppose again No. 2314 to be calling No. 2745 connected to the other substation *S*-1. A line switch at *S*-2 would be operated first, then a first selector and a second selector at *A*. This second selector would extend the connection over a trunk to a connector switch located at *S*-1. This switch would be operated by the impulses corresponding to the last two digits of the desired number, and would complete the connection to line and telephone No. 2745.

Suppose again, No. 2314 to be calling No. 2536 connected to the same sub-station, *S*-2. In this case, a line switch at *S*-2 would, as before, extend the connection to a first selector switch at *A*. This switch would extend it to a second selector at *A*, which would extend it back over another trunk to a connector switch at *S*-2. This connector switch would complete the connection to line and telephone No. 2536. During such a conversation, therefore, two trunks would be occupied between the sub-station and the office through which it operates. This indicates that a sub-station is best adapted to a district where there is very little local telephonic intercourse, because every local connection occupies two trunks without any immediate benefit.

The sub-station is also especially adapted to a small isolated district where the expense of a constant local attendant would not be warranted, and, where it is, therefore, considered advisable to install the simplest apparatus obtainable, with arrangements for supervision from the main office to which the sub-station trunks are connected. Under almost any conceivable condition a sub-station will require more trunks than a branch office, for several reasons: first, all calls must be trunked; secondly, there is one group of outgoing and one group of incoming trunks for each 100 lines connected to the sub-station; thirdly, in order to provide thorough supervision from the main office, each outgoing trunk contains three wires instead of two.

It is, therefore, seen that in considering the advisability of installing a sub-station instead of a branch office, the increased expenditure for trunk installation and maintenance should be weighed against the saving in cost of supervision and attendance.

When the proposed office is to be a small one, and the trunks to it are to be secured by converting the line cable at present entering the new office district into a trunk cable, there is often no immediate advantage in economizing in the number of trunks. To such conditions a sub-station is well suited even if the trunks are long and consequently expensive. It would appear, however, that in the present state of the art such an auxiliary to a "main" office would rarely be warranted if it contained over 500 lines.

A sub-station may often be used to much better advantage as an auxiliary of a branch office; that is, a branch may be installed at the center of a comparatively large district so that all trunks going out from or coming into the district will terminate at the centrally located branch office, then shorter and more numerous trunks may be run from this office to sub-stations located about it. As an illustration of this plan please refer to Fig. 19 in which *A* represents an office of 5000 lines, *B* a branch office of 1500 lines, *S*-1 a sub-station of 100 lines, and *S*-2 another substation of 300 lines auxiliary to the branch office. Calls would be handled as follows: suppose, for example that a subscriber No. 8712 connected to sub-station *S*-2 called telephone No. 2134 connected to office *A*. As No. 8712 operated his calling device his line switch at *S*-2 would instantly operate and connect his telephone over an idle trunk to a first selector switch in branch office *B*. This first selector would be operated as the subscriber's calling device transmitted the first digit (2) of the number being called, and would extend the connection of the calling telephone over a trunk to a second selector switch at *A* office. The second digit (1) transmitted from the calling telephone would operate this second selector and extend the connection to a connector switch also located at *A*. This connector switch would be operated by the last two digits (3 and 4) of the number called, and would complete the connection

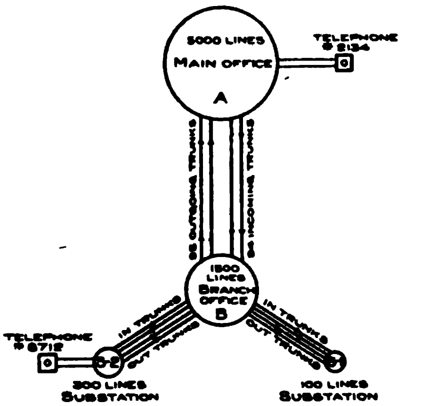


FIG. NO. 19

NUMBERS IN "A" OFFICE RUN FROM 1000 TO 5999
NUMBERS IN "B" OFFICE RUN FROM 7000 TO 8499
NUMBERS IN "S-1" OFFICE RUN FROM 8600 TO 8699
NUMBERS IN "S-2" OFFICE RUN FROM 8700 TO 8999

to the line and telephone No. 2134. It might be of interest to note in passing that the current for the transmitter of the calling subscriber would be furnished from the battery located at *B* and the current to the called subscriber's transmitter from the battery located at *A*. If the call should proceed in the reverse direction, that is, if No. 2134 connected to *A* should call No. 8712 connected to *S*-2, then the operation of a line switch and a first selector switch at *A* would extend the connection over a trunk to a second selector at *B* which would in turn extend it to a connector switch at *S*-2. This connector switch would complete the connection to line and telephone No. 8712.

Supposing the number of calls made per line per day in this 6900 line system to be 16, and the number of busy hour calls to be one-eighth of the total, and that the "community-of-interest" can in all cases be taken care of by the factor 0.75, then the number of incoming trunks necessary to *B* from *A* would be 94, and the outgoing trunks to *A* from *B* would be 95, a total of 189. This number is 9.9% of the total of 1900 lines in the branch office district. The number of pairs of wires necessary for incoming and outgoing trunks, supervision, furnishing ringing current, charging substation battery and all other purposes between *B* and *S*-2 would be 78; that is, 26% of the 300 lines connected to the sub-station, and between *B* and *S*-1 would be 28 pairs, which equals 28% of the number of subscribers' lines connected to that substation.

In order to demonstrate the advantage that there may be in making the office *S*-2, for example, a sub-station instead of a "branch" office, the writer would direct attention to Fig. 20, in which is represented the same system as that in Fig. 19, except that the office *S*-2 is now considered to be a branch office of "B". *S*-2 would now contain first selector and second selector switches in addition to the line switches and connector switches. There would be no difference in the mode of operation so far as incoming calls to *S*-2 were concerned, but there would be a difference in the method for handling outgoing calls; also all local connections would be completed inside of the *S*-2 office. The principal difference in the outgoing connections would be that connections from *S*-2 to *A*, instead of passing through switches at *B* would be trunked direct from the first selectors at *S*-2 to second selector switches at *A*. The effect of this would be to increase the number of groups of trunks and consequently the number of circuits necessary between *A* and the *B* districts, so that with the particular case illustrated in Fig. 20 the total number of trunks between *A* and *B* would be increased by 15, while a reduction of only 12 circuits would be secured between *B* and *S*-2. It is, therefore, readily seen that if the distance from *A* to *B* is equal to, or greater than, the distance from *B* to *S*-2, that the branch office scheme in Fig. 20 would require more trunk mileage than the sub-station scheme in Fig. 19. The writer believes that this fairly illustrates the advantage that there may often be in using the sub-station as an auxiliary of a branch office.

As an illustration of how trunking of calls is done in a larger automatic system, Fig. 21 shows a rough skeleton of a 50,000-line system. This contains 5 main offices, *A*, *B*, *C*, *D*, and *E*, of which *A* has 8 branch offices and the other main offices each have 5 branch offices. Since this system has an ultimate capacity of 100,000 lines, all numbers would have five figures, but, as is customary, in place of the first figure a letter is used, which not only makes the number easier for the subscriber to remember, but also designates the office to which the number

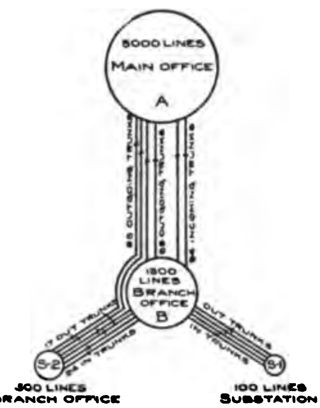
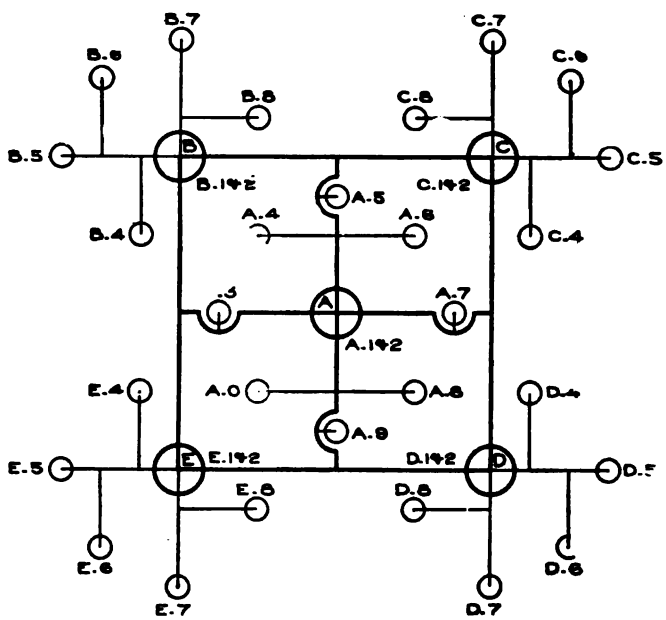


FIG. No. 20

NUMBERS IN "A" OFFICE RUN FROM 1000 TO 5999
NUMBERS IN "B" OFFICE RUN FROM 7000 TO 8499
NUMBERS IN "S-1" OFFICE RUN FROM 8600 TO 8699
NUMBERS IN "S-2" OFFICE RUN FROM 8700 TO 8999

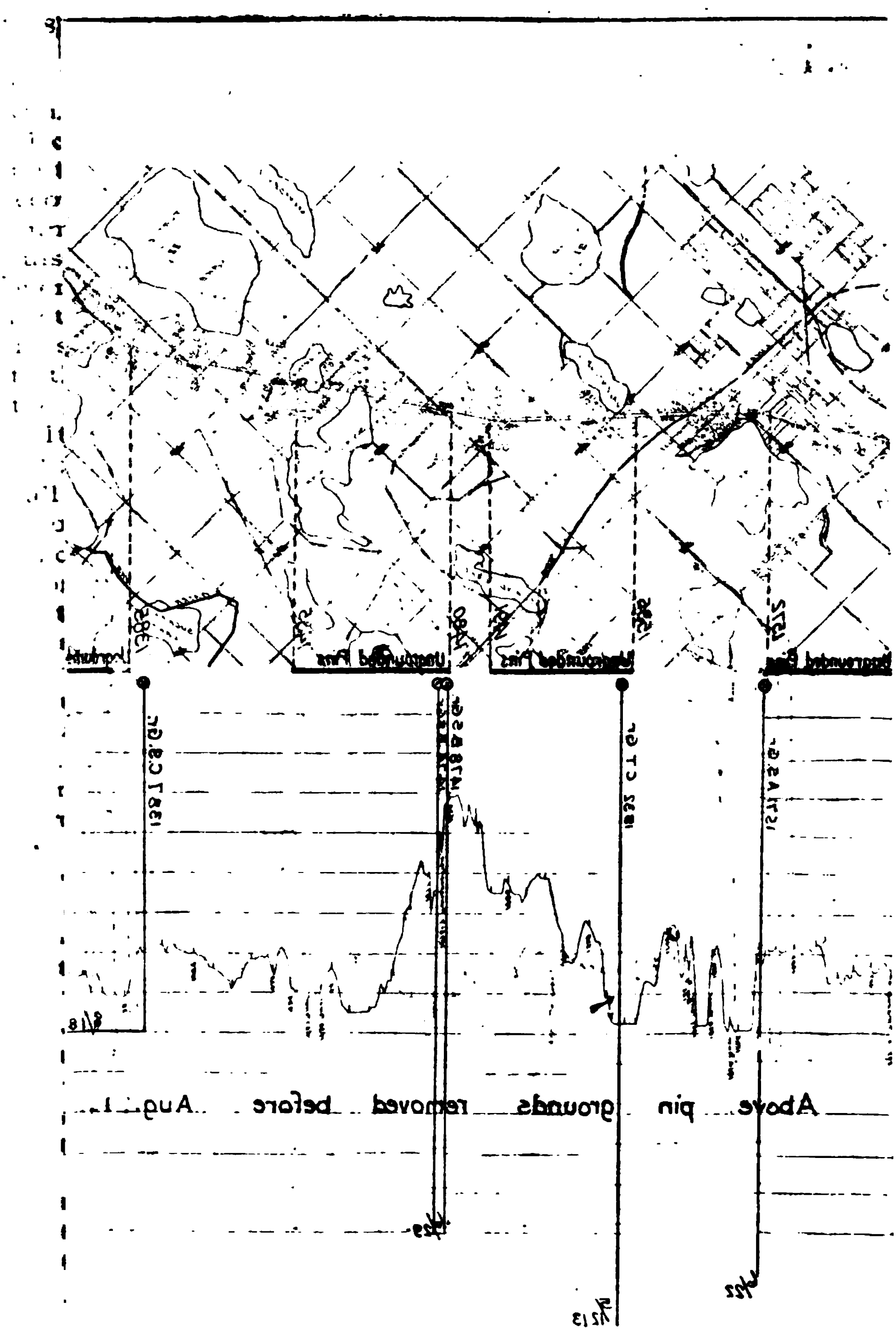
belongs. It is supposed that the main office *A* contains equipment for 2000 lines, the numbers of which run from 1000 to 2999; and that each of its branches contains equipment for 1000 lines, the numbers in *A*-3 running from 3000–3999, in *A*-4 running from 4000 to 4999, etc. Each of the other main offices is also supposed to contain equipment for 2000 lines, the numbers of which run from 1000 to 2999 in each. Of course, there is a letter prefix to each number corresponding to the office to which the number belongs. Each branch of the offices *B*, *C*, *D* and *E* is supposed to contain 1000 lines. The numbers in B-4, for example, run from 4000 to 4999, those in B-5 run from 5000 to 5999, etc.

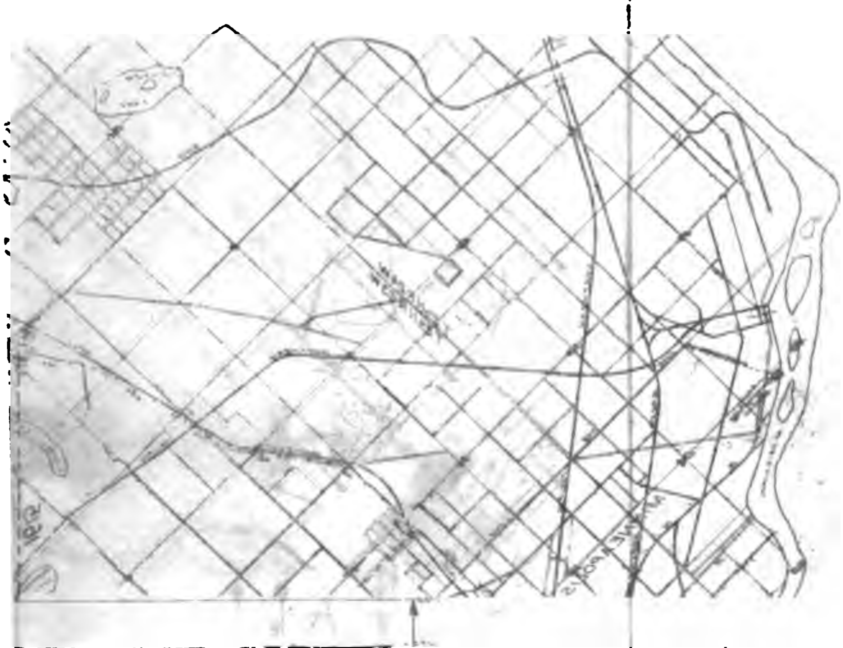
Connections in the system would be handled as follows:

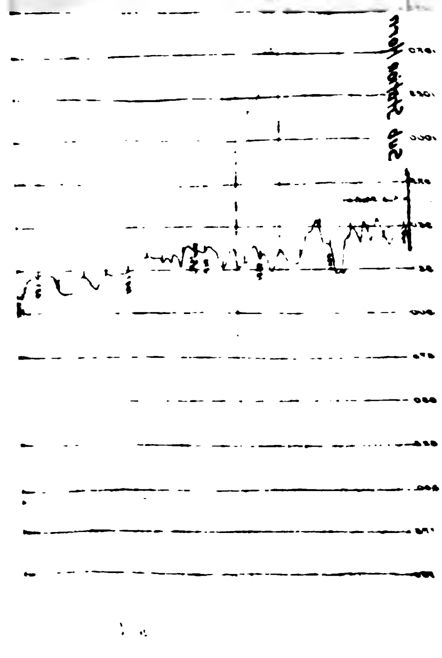


Skeleton of Divided 50,000 Line
Automatic System.
Fig. No. 21

suppose a subscriber E-7234 connected to branch office E-7 called A-5124 connected to the branch office A-5. The first movement of the subscriber's calling device would operate his line switch and connect his line to an idle first selector in his own exchange, E-7; then when the calling device sent in a num-


Ungrounded Pins
Ungrounded Pins
Above pin grounds removed before Aug. 1





LEGEND

⊙ = Punctured Insulator

● = Broken Insulator

A,B and C refer to the three phases.

S = Side insulator

T = Top insulator

Gr = With pin grounded

ufr = Pin not grounded

Tr. = Tower

Dates refer to storms during which insulators were damaged ber of impulses corresponding to the No. *A*, his first selector would be operated and would pick out an idle trunk to a second selector in exchange *A*. The second set of impulses corresponding to the figure 5 sent in by the calling device would operate the second selector at *A* and extend the connection over an idle trunk to a third selector in the office *A*-5. The next set of impulses corresponding to the 1 of the desired number would operate a third selector at *A*-5, which would extend the connection to a connector switch in the proper " 100 group " at *A*-5. This connector would be operated by the impulses corresponding to the last two digits of the desired number and would complete the connection to line and telephone *A*-5124.

It may be noted that on this call the connection to *A*-5 passes through the main exchange *A*. This would be true of every call incoming into the *A* district; that is, all trunks incoming into the district would terminate in second selectors in the *A* office. These second selectors would extend each incoming connection to a third selector located at the *A* main office, or at the branch corresponding to the thousands digit of the particular number being called. This concentration of the incoming circuits simplifies the trunking arrangement and also reduces considerably the number of trunks entering the district, because the number of groups of incoming trunks would be nine times as great if each of the nine offices received its calls, coming from outside the district, direct instead of having them come through the main distributing office *A*. It should be noted on the other hand that the outgoing call from *E*-7 does not operate any switch at its main office *E*. It would probably be preferable, however, to have the trunk pass through the cross connecting frame at *E*. In a similar manner all outgoing trunks from each of the branch offices of *E* district could be terminated on the distributing frame at *E*, and there be cross-connected to what might be called a " through trunk cable " to each of the other main offices. If a subscriber connected to any office in the *A* district should call a number connected to an office in *E* district the incoming trunk to *E* district would terminate in a second selector switch at main office *E*, and would be passed on by it to the desired branch office or thousand group. In the skeleton diagram no trunk cables are shown interconnecting the branch offices of a district; for instance, no interconnection is shown between E-6 and E-7. If desired such trunks could be put in, or the outgoing trunks from all the branch offices of *E* may, as already stated, be run to the main central office and there be cross connected on a distributing frame. This would in many cases be the most economical arrangement, because with division carried to the extent that it is in this diagram the number of trunks required between *E*-6 and *E*-7 would be comparatively small. A call from a subscriber at *E*-7 to a subscriber connected to *E*-6 would operate a line switch, first selector and second selector at *E*-7 and a third selector and connector at *E*-6 so that it is not necessary that the connection should pass through the main office *E*.

If a manual system should be divided up in the manner shown in Fig. 21, supposing for the moment that such a division would be practical with equipment of that type, then the branch office *E*-7, for instance, would have 32 different groups of outgoing trunks; that is, one group for each of the other offices in the system, and would have the same number of groups of incoming trunks. With the automatic branch office arrangement, *E*-7 has but 10 groups of outgoing trunks; that is, one group to each of the other district main offices and one group to each other " thousand section " in use in its own *E* district. *E*-7 would have but 5 groups of incoming trunks; that is, one group from each of the other offices in the *E* district. It is, seen, therefore, that by using the main offices at centers of comparatively large districts and then surrounding each main office with smaller branches, all subscribers lines may be made very short and the use of the " through " trunks between the main offices for interconnecting districts makes the trunking system comparatively simple.

It is probably unnecessary to add that in planning such a system as is represented by Fig. 21, a careful engineering study should be made for each branch office to determine whether the trunk mileage required would make a " branch " office or a " sub-station " the most economical arrangement.

One of the peculiarities of the telephone business, especially when there is competition, is that an operating company is compelled to take on the new business offered. It must keep up with its rival or drop out of the race. A user of electric light doesn't care how many other customers are connected to the same plant that he is, but a telephone user is, of course, very much attracted by the larger of two lists of subscribers. Unfortunately a one-office plant is somewhat like a water or gas plant, in that new customers cannot be constantly added by simply connecting their service pipes to the mains originally installed. Some day a point is reached when the mains are supplying all the flow of which they are capable and it is necessary to go back to headquarters, dig up the streets anew, and put in more mains or larger ones. So in a one-office telephone system, if the growth is more rapid than anticipated, as it often is, or if the growth of the city takes place in an unexpected direction, as it frequently does, it becomes necessary to remodel the cable and wire plant to suit the new distribution of business.

A one-office telephone plant sometimes must be almost entirely rebuilt within a few years of its installation in order to adapt it to a shifting of population, or to make it adequate for the customers unexpectedly demanding service.

With a multi-office automatic system this need not be done. If an unexpected demand for telephones develops in a certain section of the city, it is not necessary to put in more conduits and cables or to replace present cables with larger ones to take care of the demand, but the situation is readily and practically met by putting in a substation or a branch office in the congested district. The present line cables running to the district may be used as trunk cables to the new office. Thus the traffic carrying capacity of the cable and conduit plant reaching any district may be greatly multiplied without any additional expenditure for cable or duct. Consequently, one of the most attractive features of an automatic multi-office system is that it affords a stable value to the investment in wire, cable, and conduit.

DISCUSSION ON " A STUDY OF MULTIOFFICE AUTOMATIC SWITCHBOARD TELEPHONE SYSTEMS." ATLANTIC CITY, N. J., JUNE 29, 1908.

A. B. Smith: For a number of years it has been my hope that the automatic would be able to solve the telephone problem for large cities; that it would bring the rental a little lower for the benefit of the many who need the telephone but cannot now afford it, and that it would afford relief from the party line. That this can only be done by subdivision into small offices with short subscriber lines is acknowledged, but the apparently insurmountable obstacles of trunk lines and office expenses have stood squarely in the way. However, it may now safely be said that the automatic has arrived at that point of development where its claims merit serious consideration.

With regard to the claimed flexibility of the system in being able to use subscribers' lines for trunks, I ask if it would not seriously interfere with the practice of making trunk cables of lower resistance and electrostatic capacity than subscribers' cables? It would necessitate making the whole installation of cables good enough for trunks, which would be very expensive.

In a continuously growing city the telephones increase in number in two ways—increase of density and increase of territory. If merely the telephone density increased, and the transmission equivalents had been properly cared for, any district might be converted into a branch office and old subscriber lines used for trunk lines with no loss. But all around the edge of the city the telephone exchange is expanding and the length of lines increasing, so that to continue indefinitely with the process would eventually make transmission very poor. In this respect the automatic offers no additional advantages except as it makes profitable a smaller branch office.

In a multioffice automatic exchange the trunk repeater is used to relay the calls and permit each subscriber to draw talking current from the nearest battery. This introduces added complications into the selecting mechanism, but as far as talking is concerned a little comparison will show the conditions. In the common battery manual trunk circuit there are two repeating coils between the two subscribers, one in the cord circuit at the *A* board, the other in the trunk circuit at the *B* board.

No repeating coils are used in the automatic, their place being taken by the condenser-retardation coil combination so common in independent cord circuits. From a test which I recently made, the repeating coil is considerably less efficient as a transformer of speech than the condenser-retardation coil combination. Hence the insertion of the trunk repeater into the line will still leave the automatic with an excellent transmission circuit.

Where there are a number of groups of trunks from one office district to another, as from E to A, Fig. 21, it seems that there would be considerable advantage in making all the trunks more or less accessible to all the offices in that district. I ask Mr. Campbell if this can be done? If so, the number of trunks can be reduced and still have the same busy hour capacity as a whole.

For the benefit of many who may not now take kindly to the idea of an all automatic plant, I ask if the line switch or some other device can be used on manual boards to trunk small groups of subscribers to the office? My idea would be to place such a switch at the center of the subscriber group with as many trunks to central as necessary. When any subscriber in the group takes the receiver from the hook, he is automatically trunked to the manual board and answered by the operator just as if he were on an ordinary line. It would enable the giving of individual line service with as few wires as would be required for party lines. Has this been suggested or worked out, and is it considered practical?

John Wicks: This paper offers encouragement to those connected with the development of automatic telephone service. Few engineers have yet given the matter sufficient thought or study to enable them to see its possibilities. The fact that telephonic connections are made automatically has been viewed as a curiosity. That the public in large communities has made use of it for years, even in preference to the best manual service offered by competing companies, is still looked upon as incredulous. Many have wondered at its rapid general adoption, but few have stopped to investigate the reason of its growth. It is therefore interesting and gratifying to learn that it has developed along a line which makes it possible to decrease the great economic waste, which in the form of idle lines is to be found in the old-style telephone systems.

Automatic telephone service has been tried sufficiently to prove itself practical. We know that the telephone-using public likes it. We know also that there are no mechanical or electrical difficulties in the art which cannot be overcome. To compete with manually operated telephone systems, therefore, it has only to prove itself economically more efficient than its rival.

In manually operated exchanges, party lines were long ago resorted to as a part solution of the problem involving the reduction of the percentage of idle lines. So important has this branch of the service been considered that a prominent telephone engineer stated only a few years ago that a grave objection to the automatic equipment was that it had no party lines. The manufacturers of automatic switchboards have since then successfully solved the party-line problem, but it is hoped that the introduction of multioffice automatic switchboards will eventually do away with a large part of party-line service without putting the rental above the reach of present party-line subscribers.

The principal reason for the moderate price of party-line service is the saving effected in line construction by using one line for several telephones. A similar reduction in line investment is obtained by the use of a large number of small offices interconnected by trunk lines. It has the advantage of offering individual lines to patrons who can now afford only party lines.

A plan has been proposed and is now about to be tested in an eastern city which, if successful, will enable a telephone company to offer a still cheaper direct line service. This new service might be termed "limited trunk" service, because the scheme is to limit the number of trunks to the main office from the district station to which the limited trunk subscribers are connected. For example, if 100 telephones, instead of being connected to the main central office by 30 or 40 party lines, should be connected individually to a 100-line switch unit in a district station, this district station may then be connected to the main central office by a number of trunks less than that necessary for furnishing each telephone a trunk line whenever demanded. For instance, the number of incoming and the number of outgoing trunks connected to the line switch unit might each be limited to five, thus making a total of 10 trunks instead of 30 or 40 party lines. It can readily be arranged so that any party attempting to call when all of the trunks outgoing from the district station are busy, will receive either the ordinary busy signal, or preferably a peculiar signal, which will inform him that all trunks are occupied for the moment and that he should call again in a few minutes. It often happens that one subscriber keeps a party line busy for an unnecessarily long period to the inconvenience of others on the line, but it would be impossible for any one or two inconsiderate subscribers to occupy all of the trunks from a district station. Another marked virtue of this limited trunk service is that communication would be absolutely private, thus eliminating one of the most objectionable features of party-line service.

There may be questions raised as to the advisability of having a small sub-station with its apparently complex line switches and connectors without an attendant, but experience has proved that even the operation of large switchboards contained in one room is done to a large extent through supervising signals. If a line becomes grounded or open, or if something goes wrong with the switching mechanism, attention is called to the matter by means of a signal, which may as readily be made to appear in another office miles away. Should the trouble be in the subscriber's line or instrument, no other part of the sub-station is affected, whereas a trouble in a party line will frequently throw all the instruments connected to that line out of service. Any part of the switching mechanism going wrong will affect only the trunk connected to that particular switch, and that can be made "busy" from the main exchange until it is convenient to repair it.

Apparently, rural or extremely isolated subscribers would still have to be furnished party-line service, but it would appear that multioffice and limited trunk multioffice service might be used both to the advantage of the telephone company and its patrons to dispense with the majority of the party lines.

The possibilities of limited trunk service will be still further enchanced, especially for residence districts, when the manufacturers of automatic equipment put apparatus upon the market that will make two-way trunks practical. It will then be unnecessary to have one group of trunks for handling outgoing calls and another group for incoming calls, but each trunk will be available for a call going in either direction. It is a well-known fact that the maximum flow of traffic from the residence districts to the business district of a city does not occur at the same time as the maximum flow in the opposite direction. Consequently, if the trunks could be used in either direction a less number would be needed. Two-way trunk equipment is possible, in fact has been tried experimentally a number of times during recent years. It is my belief that it will eventually be made a commercial success.

E. A. Mellinger: Practically the only argument which can at the present day be consistently advanced against the automatic system is the first cost of the apparatus, which, as indicated in Fig. 5, is considerably greater for a single automatic exchange than for a single manual exchange, except in cases of very large switchboards. In some instances this is a factor of more immediate importance in deciding what equipment shall be installed than is the comparative cost of operation and maintenance.

Mr. Campbell demonstrates the entire practicability of subdividing the automatic exchange to an extent not economically possible in manually operated switchboards. It is probable that, even with a comparatively limited subdivision, from 50% to 75% of the cable required for a single exchange can be eliminated. In comparison with the economy thus effected the additional first cost of the automatic switchboard is of small importance.

Since the cost of maintenance and operation of an automatic exchange is almost inappreciably increased by subdividing it into branches of 1000 lines or more, and since, obviously, the service is unaffected by such subdivision, the only items to be considered are the slightly increased cost of apparatus and buildings. With reference to the cost of apparatus, there can be no doubt but that there will be some increase with subdivision, owing principally to the present necessity for separate battery-supplying units; but in many instances there would be an actual saving in the cost of building, on account of the comparatively low value of building locations required for the branch offices. The central exchange is usually located of necessity in the heart of the business district where land values are at the highest, and any reduction in space required here would much more than compensate for a corresponding increase in branch office space. It is probable also that less expensive building construction could be employed in branch offices than in central exchanges.

For the small sub-station serving an outlying district it is customary to rent space in some office or store building, or to erect a small building for housing the apparatus; but in an exclusive residence district it is sometimes difficult to obtain space in a suitable location. In at least one instance this difficulty has been successfully met by placing the sub-station under ground in a moisture-proof cement vault, similar to those used for housing batteries in railway signal work. The most logical location for a sub-station is usually at the manhole where the cable distribution for the district begins, and since no serious objection has been encountered in the installation and operation of the underground sub-station, there appears to be no reason why the manhole itself cannot be constructed to accommodate the switching apparatus, thus eliminating the necessity for building space.

The vault, or monolith as it is called, to which reference is made, was constructed complete in one piece before being lowered into place. It is elliptical, its dimensions being 4 ft. 10 in. by 7 ft. 8 in. by 6 ft. high, and accommodates a 100-line unit together with protector and distributing rack, batteries, etc. The average manhole is almost as large.

Carefully kept thermometer and barometer records indicate a practically constant temperature of 70 degrees fahr. and an almost complete absence of moisture, except as the presence of the troubleman or others in the vault for half an hour or more changes the normal atmospheric conditions. After such visits the vault is quickly dried by lighting an incandescent lamp for a short time. A small ventilating fan would doubtless prevent any moisture precipitation while the vault is open.

Every city has one or more telephone districts so far removed from the telephonic center that the installation of the substation is an economic necessity, particularly since the telephones in these districts usually yield smaller rentals than those centrally located. Such districts are being satisfactorily served by trunking stations of from one to five hundred lines in a number of automatic exchanges in various cities, but the limit of practical distribution appears by no means to have been reached. It is more than probable that in the not very distant future every large office or apartment building will have its sub-station trunking to the nearest branch exchange, even though the distance be only a few blocks, and that these trunking stations will in most cases be a part of the underground system.

From the underground sub-station to the underground branch exchange is not a long step, and although the branch office is usually of such size as to require the constant presence of one or more attendants, the necessity for artificial light and ventilation is hardly to be counted as a serious objection. The economy which could be effected in the business center of large cities by such an arrangement is apparent.

Morgan Brooks: Mr. Campbell's paper speaks of the economic waste represented by 90% of the wire plant being idle even in the busiest hours. Imagine, if you please, a much smaller waste, such as 50%, and it is evident that the busy signal would be received from half the calls. Good service demands a minimum of busy signals, and necessitates economic waste. The author has shown that the quickness of disconnection characteristic of the automatic system helps the service, especially with trunk lines, although it evidently increases the percentage of non-use. It is only in private branch exchanges that good service may be coupled with a reasonably large load-factor of subscribers' lines.

L. E. Hurtz: A word or two about these sub-stations. Mr. Campbell speaks from the manufacturer's point of view; I speak from the operator's point of view. A very large advantage in the use of these sub-stations over the ordinary type of equipment is the fact that the exchange can be divided into units as small as one hundred lines. When considering the cable distribution of a telephone plant, the reasons that make it necessary to subdivide very large districts into several smaller ones are well understood. The question then arises as to the proper time to stop sub-dividing. In manual practice, on account of the cost of buildings and equipment and in order that satisfactory and economical service can be given, these branch exchanges vary in size from 1,000 to 10,000 lines, according to the density of the telephone development in that vicinity. With the use of low-priced buildings and low labor costs it is practical with these automatic switching units to reduce the size of these branch exchanges to one or several hundred lines, which increases the savings due to sub-division to a corresponding extent.

In our experience of a year and a half, during which time we have had two sub-stations in operation, we find we can give high grade service with but little additional labor. It is an easy matter to realize what vast savings can be made in the cable plant by use of this system. The saving in investment and maintenance cost and interest cost must be equated against the additional labor; if the additional labor item is low enough there is a big saving. This system is being tried in several places. Our experience with it leads me to believe that it is thoroughly practical and will work out as well as indicated by Mr. Campbell.

I am convinced that one of the greatest developments made in telephony in recent years is the production of this switch unit. It is possible now to put in sub-stations as small as one hundred lines, locating them at isolated points, and at the same time not increase the operative and maintenance expenses to any considerable extent.

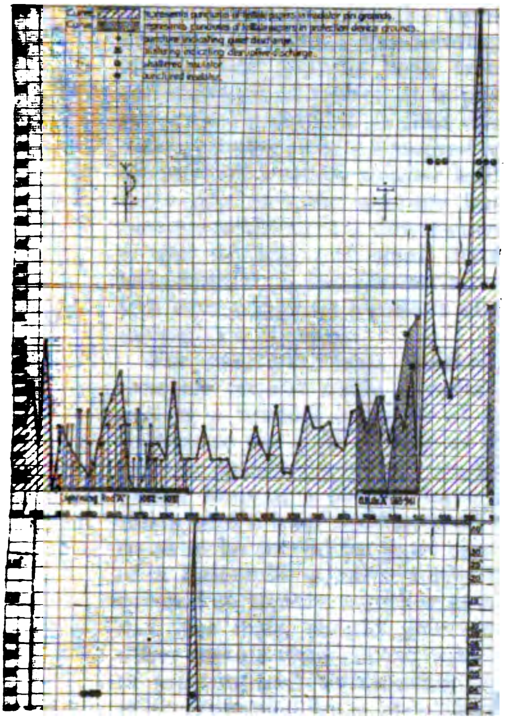
Samuel G. McMeen (by letter): The economic waste of which Mr. Campbell treats has been recognized for many years, and efforts have been made to reduce it in manually operated systems. In most of the cases the effort has been successful. The method of waste-reduction by automatic apparatus, as treated by Mr. Campbell, is the most important recent attack, and is one from which a very large amount of new knowledge may be expected to be drawn.

The broad idea of dividing a telephone exchange wire-plant into two general parts, and then using one part at a high efficiency and the other at a low, is not new. It has been proposed again and again, and has been developed for various forms of apparatus and various arrangements of wire-plant. The planetary system of operating manual equipment was such an effort, proposed eight or ten years ago by Mr. Angus S. Hibbard. In that system all calls needed to be trunked from a small local office, in which they were first received, to a central switching office, even though they might need to be trunked right back again to the small first office to find the sought lines.

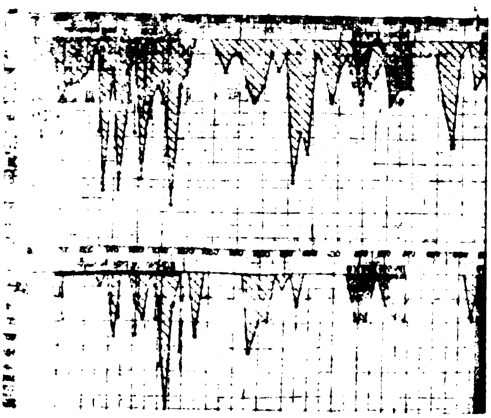
The telephone requirements of the business area of every city are served very largely by private-branch exchanges, privately operated. About two-thirds of the traffic originating in them requires to be trunked to a main exchange operated by the telephone company. If these private exchanges were to trunk *all* their originated business, even at the cost of receiving again all local calls, such a plan would be a *manual* counterpart of the waste-saving system Mr. Campbell describes. As it is, the plan is a real counterpart so far as concerns the traffic for which, mainly, a private branch exchange exists, and the object is the same—to save wire-plant at a cost for apparatus and attendance.

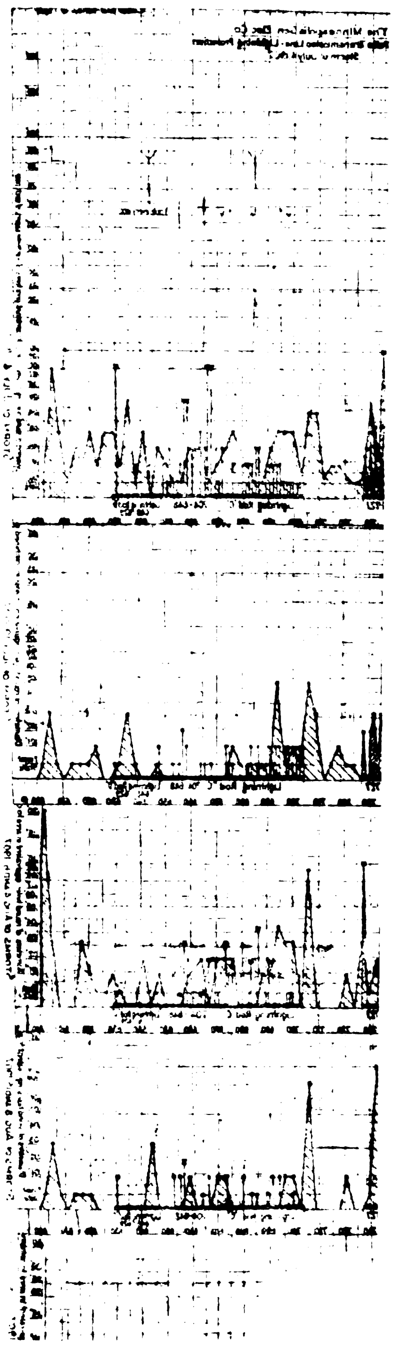
A proof of the widespread wish to make such a wire-plant saving is to be seen in the long effort to produce a selective and secret party-line equipment. It is possible to-day to have and use such a party-line system, but at best the privileges of the line are divided among the subscribers upon it. None has the same good condition as the subscriber on a single pair of wires, all his own. In either manual or automatic practice, the amount of central office equipment is controlled by the traffic, which party-lines do not reduce, unless by discouragement caused by poorer service. All that a party-line can do, at best, is to save something of the annual cost of its line, and unless this line be longer than a certain minimum, nothing at all is gained, and always something in quality of service is lost.

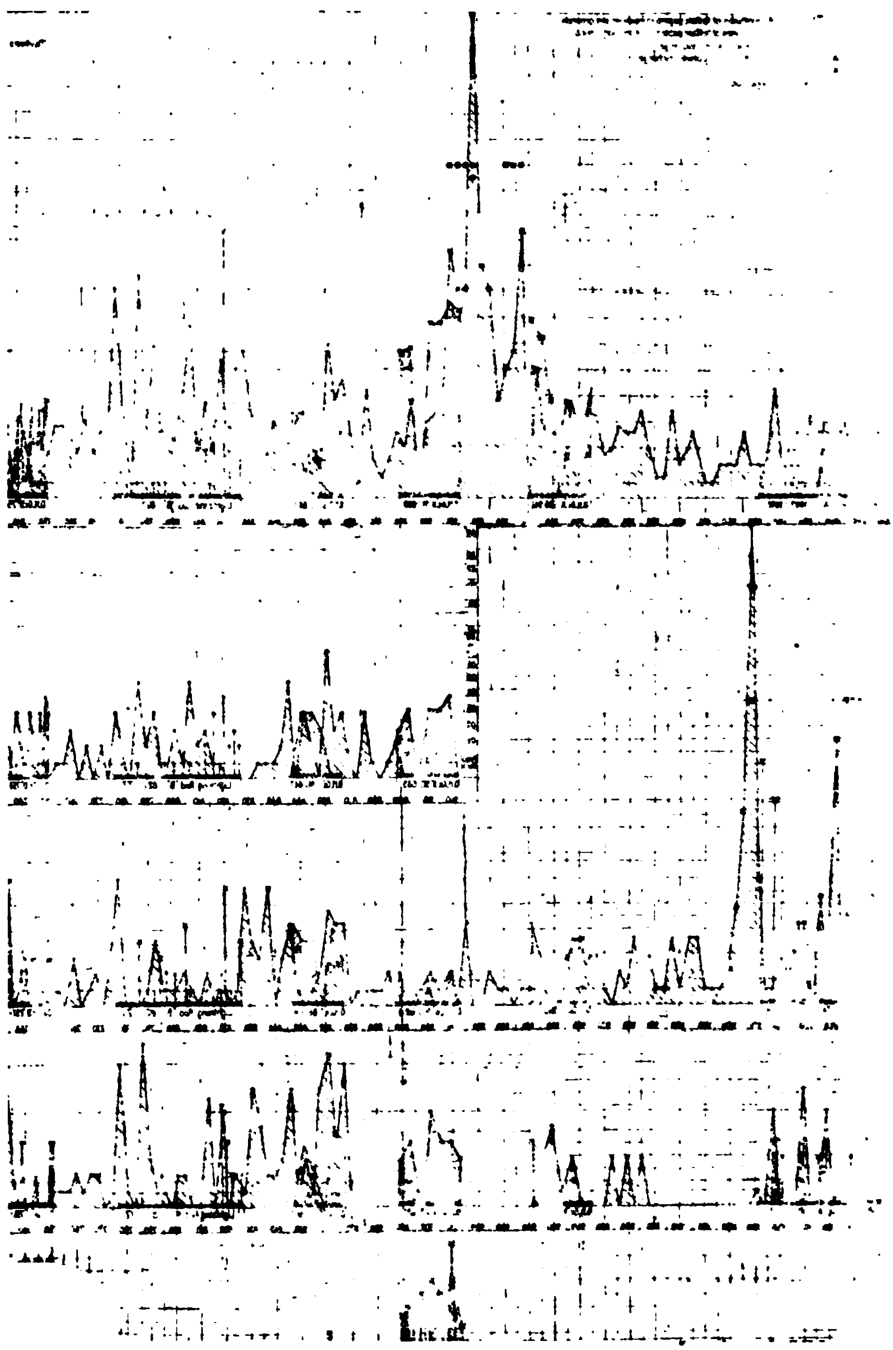
A condition not brought out by Mr. Campbell may well be considered as next in importance to the savings he treats of. I refer to the saving possible in the *character* of lines, as distinguished from their *extent*. The subdivision of the plant, so as to have many and short subscribers' lines, connecting over long and few trunk lines, enables the kind of circuits of both sets of lines to be reviewed with great gain. What I mean is this: the facts which govern the choice of circuit elements for subscribers' lines are much dependent upon distance. The conductivity of the sub-



17—Enlargement of part of complete R







scriber's loop governs the amount of current deliverable to his transmitter from a fixed-voltage central source. The capacity of the loop governs both transmitting and receiving. For a set standard of either, it is possible to distribute the lines of a subscriber's district, if that district be small, through cables of much smaller wires squeezed into a much smaller bundle and covered by a much smaller lead sheath, than if the district be a large one and the average lines be long. As the transmitter current problem is a direct-current distributing one, the analogy is that of large and small districts in direct-current power distribution, with the further advantages that the telephone problem involves great numbers of circuits, in each of which a small saving can be made.

For example, most subscribers' lines in multioffice manual practice require cable circuits of No. 22 B. & S. gauge wires, having a mutual capacity of not over 0.06 mf. per mile and a resistance per mile of loop of about 190 ohms. Assume that a system satisfies working conditions with such cables when the longer lines of a district have a length of somewhat under two miles and a loop resistance of, say, 350 ohms. If it were recast so as to be served by more centres, with maximum lines in each of a half-mile, a cable formed of No. 28 B. & S. gauge wires, pressed so tightly together as to have a mutual capacity of 0.22 m.f. per mile, should give similar results. Equally, wires of other metals than copper may be used, with a gain in certainty of jointing and terminating, and the reduced sheath diameter is accompanied by a reduction in its thickness.

The foregoing presumes that each small district contains its own source of current, so that the calling and the called subscriber each receives transmitter current over the minimum length of line. Experience with operating conditions shows this to be a preferred arrangement, for reasons other than transmitter supply; and the increased efficiency of transmission in private branch exchanges having localized current sources for trunked connections emphasizes the point.

Mr. Campbell's observation of the shorter holding of the line in an automatic system seems to be generally noted. It is a psychological matter more likely to be discovered than predicted. The same is true of quicker answering and less waiting for answer after actual ringing has been done. These differences in the actual performance of the two systems need to be considered in any study involving comparisons. The longer time of *initial* holding of interoffice trunks seems also to be overbalanced by the speed of disconnection in the automatic apparatus, and to this must be added a consideration of the slowing down of disconnecting efficiency on the part of the manual *B* operator during the rush period.

No casual study of large city work fails to show the beginner the influence of sub-division of districts on the amount of trunking. The percentage of calls trunked out of the New York

Cortlandt Street subscribers' board in 1896 was 75; in 1902 it was 90 or more, and to-day, under accepted manual practice for such surroundings, it is 100; that is, it is not worth while to complete any call directly in a manual multiple of lines when so few as a tenth of them can be so completed. Mr. Campbell's point of trunking all calls in an automatic system is of equal force in view of that tendency in manual practice, and of the present trend of thought in partly automatic manual systems.

A feature on which more might have been said is the possible danger of excessive changing of subscribers' numbers. It must be admitted that anything which endangers a subscriber's privilege to keep the same telephone number through a term of years is a bad thing. In a one-office exchange that danger is least, and under ideal conditions may be nothing, for the main distributing frame in that one office enables the central office equipment to follow up his line, into whatever quarter of town he may move. But in a multioffice system, it is a penalty upon the subscriber that he must change his number when he moves from district to district. The more districts there are, the worse it is for him. But it is further a hardship that in cases of relief of congested regions, as suggested toward the close of the paper, a subscriber may awake to find his number changed overnight, through no fault of his own. Certain care in districting regions, and certain stubbornness in following the resulting plan, will prevent a large part of the changes required by future splitting of original sub-office districts. It is strongly to be recommended that this forecasting be done, for the number-changing evil is one in which party-line and sub-office systems are alike.

W. Lee Campbell (by letter): Professor Smith asks if it is possible to make all of the trunks from *E* office to *A* office in Fig. 21 accessible to all of the subscribers. It is possible, in fact, equipment of the necessary type has already been installed for trial and is operating satisfactorily.

He also asks if line switch sub-stations could not be used with manual telephones in connection with a manually operated central office. I would reply that they could be, and probably will be.

Concerning the plan for relieving a congested district by converting the line cable into a trunk cable, I wish to say that this would often improve transmission from the original telephones, because it would bring the battery closer to the transmitters drawing current from it.

This feature might even permit the district to be enlarged; that is, new patrons farther away might be added and their transmission be equal to that afforded the original subscribers, before the new local office was installed.

I think that in economically designed plants the conductors of the trunk cables are not made heavier than the lines, unless the distances are so great that heavier wire is necessary to keep the transmission up to standard. In other words, the subscribers in the district reached by such a cable would have to be served by heavier conductors if no branch office were installed in that district. I see no reason, therefore, why adding to the number of offices should increase the amount of large conductor cable used for trunks; it appears to me that it would tend to decrease the amount.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N.J., June 29, 1908.

WIRELESS TELEPHONY

BY R. A. FESSENDEN

SYNOPSIS

During the course of this work, now extending over twelve years, since 1906, I have naturally incurred indebtedness on all hands. Amongst others to whom my thanks are due are: Professor Kintner for much valuable assistance in the experimental work; Mr. Brashear, for his kindness in making up a number of special pieces of optical and other apparatus for use in the work; Mr. H. W. Fisher, and to Professor Frost, for the loan of electrical apparatus. For the development of the high-frequency alternator, I have to thank Messrs. Steinmetz, Haskins, Alexanderson, Reist, Geisenhoner and Dempster, and Mr. Guy. For much valuable assistance in the construction of my transatlantic apparatus, I am obliged to Mr. Green. Especially am I indebted to the gentlemen who have acted as my assistants during the progress of the work, especially Mr. Stein and Mr. Mansbendel and Mr. Bennet, Mr. Davis, Mr. Hill, Mr. Kroeger, Mr. Boyle and Mr. Bryant, and to our shop superintendent, Mr. Williams.

In order to avoid repetition, patents covering inventions made and developed by the writer without assistance or coöperation are referred to by the patent number and date only. Where there has been cooperation on the part of an assistant the patent has been taken out and referred to under the joint names of the coöperators. All inventions made or developed by assistants are taken out and referred to by the assistant's name.

4. Fundamental differences between the old and new wireless schools.
5. Period 1898–1902.
    (a) Development and perfecting of sustained oscillation-non-microphonic receiver method.
    (b) Further development of damped wave-coherer method.
6. Period 1902–1908. General abandonment of old method and adoption of new method. Later developments.

C. Theory of wireless telephony.
D. History of development of wireless telephony.
E. Methods and apparatus.
F. Operation.
G. Possibilities.
H. How wireless development has been prevented by governmental action.
I. Considerations.
K. Appendix.

A. Preface

The discussion of the theory, practical operation, and possibilities of wireless telephony is facilitated by first briefly considering the history of the development of wireless signaling generally.

B. Brief History of the Development of Wireless Signaling

1. *Introduction.* In preparing this note it has been considered best, for the sake of accuracy, to refer to published results, such as scientific articles or theses or patent specifications. For the sake of brevity, references to work done in repetition of previously published work has as a rule been omitted. So far as possible, the expression of personal opinion has been avoided in this section of the paper, the object being to gather together in concise form the facts known in regard to the development of the art. With the exception of Munk's original paper, which could not be obtained, all references have been verified by consulting the original publications, a work of some labor, and if any omissions or mistakes have been made data for their correction will be much appreciated.

2. *Period* 1838–1897. *Origin and Development of Old or Damped Wave-coherer Method.* Joseph Henry, to whose work

the development of wire telegraphy owes so much, was the first (1838-1842) to produce high frequency electrical oscillations, and to point out and experimentally demonstrate the fact that the discharge of a condenser is under certain conditions oscillatory, or, as he puts it, consists "of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained ".[1]

This view was also later adopted by Helmholz[2] but the mathematical demonstration of the fact was first given by Lord Kelvin in his paper on " Transient Electric Currents ".[3]

In 1870 Van Bezold discovered and experimentally demonstrated the fact that the advancing and reflected oscillations produced in conductors by a condenser discharge gave rise to interference phenomena.[4]

Professors Elihu Thomson and E. J. Houston in 1876 made a number of experiments and observations on high frequency oscillatory discharges.[5]

In 1883 Professor Fitzgerald suggested at a British Association meeting[6] that electromagnetic waves could be generated by the discharge of a condenser, but the suggestion was not followed up, possibly because no means was known for detecting the waves.

Hertz[7] discovered a method of detecting such waves by means of a minute spark-gap and before March 30, 1888, had concluded his remarkable series of researches in which for the first time electromagnetic waves were actually produced by a spark-gap and radiating conductor and received and detected at a distance by a tuned receiving circuit.

Hertz changed the frequency of his radiated waves by altering the inductance or capacity of his radiating conductor or antenna, and reflected and focused the electromagnetic waves, thus demonstrating the correctness of Maxwell's electromagnetic theory of light.

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1. Scientific Writings of Joseph Henry, Smithsonian Institution.
2. Helmholz " Erhaltung der Kraft ", Berlin, 1847.
3. Kelvin, *Philosophical Magazine*, June, 1853.
4. Van Bezold, *Poggendorff's Annalen*, 140, p. 541.
5. *Journal Franklin Institute*, April 1876.
6. Fitzgerald "On a method of producing Electromagnetic Disturbances of comparatively short wave lengths". *Report of British Association*, 1883.
7. Hertz " Electric Waves ".

Lodge later in the same year read a paper on the " Protection of Buildings from Lightning "[1], before the Society of Arts, in which he described a number of interesting experiments on oscillatory discharges.

Great interest was excited by the experiments of Hertz, primarily on account of their immense scientific importance. It was not long, however, before several eminent scientists perceived that the property possessed by the Hertz waves of passing through fog and material obstacles made them particularly suitable for use for electric signaling.

Professor Elihu Thomson in a lecture delivered at Lynn, Mass., on "Alternating Currents and Electric Waves", in 1889, suggested this use.

Sir William Crookes in the *Fortnightly Review* for February, 1892, discussed the matter in some detail. I quote his statement in full as it shows what a clear conception he had of the possibilities and obstacles to be overcome:

> Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.
>
> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave length of which I have spoken will easily pierce such medium, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At the present time experimentalists are able to generate electrical waves of any desired wave-length from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another What, therefore, remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers, which will respond to wave-lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver

1. Lodge *Society* of *Arts*, 1888.

(apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.

I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave-lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by his friends whose correspondence he wished to tap. By " coding " the message even this remote chance of surreptitious straying could be obviated.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The statement in the last paragraph of the quotation refers to the work of Professor David E. Hughes.[1]

Professor Dolbear also suggested the same thing in an article in Donahoe's Magazine, March, 1893.

In fact the idea of using Hertzian waves for wireless telegraphy seems to have been quite widespread in the years immediately following Hertz's publications.

Fairly efficient means of generating electromagnetic waves of any desired length had been made known by Hertz. Vertical antennas connected with the ground had been previously used for sending and receiving by Dolbear in 1882 in connection with his system for telegraphing by electrostatic induction[2] and also later by Edison and others.

Hertz's receiver, the minute spark-gap, was not suited for wireless telegraphy and before any telegraphic work could be done a suitable receiver had to be found.

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1. For Report of this work see *Electrician*, May 5, 1899.
2. Dolbear U. S. patent 350,299, March 24, 1882.

The fact that tubes containing conducting powders had their resistance altered by the discharge of a Leyden jar and that the original resistance could be restored by tapping the tube was first noted by Munk in 1835.[1]

In 1890 Branly showed that such a tube would respond to sparks produced at a distance from it.[2]

In 1892, at the meeting of the British Association at Edinburgh, Professor George Forbes suggested that such a tube would respond to Hertzian waves.

In 1893 Professor Minchen demonstrated experimentally that such powders would respond to electromagnetic waves generated at a distance.[3] He used a battery and galvanometer shunted around the powder to detect the effect of the waves.

Sir Oliver J. Lodge on June 1, 1894, delivered a lecture before the Royal Institution.[4] In this remarkable lecture Lodge described among other things the following:

1. The filings coherer.
2. The filings coherer in hydrogen under reduced pressure (this in a note added July, 1894).
3. The automatic tapper back for the coherer.
4. The metallic reflector for focusing the waves.
5. The connection of the coherer to a grounded conductor; *i.e.*, a gas pipe system.
6. The method of making the coherer so connected respond by setting up oscillations in a separate grounded system, *i.e.*, a hot-water pipe system, in another part of the building.
7. The method of detecting distant thunder storms by connecting the coherer to a grounded gas pipe system.

In this lecture Professor Lodge stated that in his estimate the apparatus used would respond to signals at a distance of half a mile.

Early in 1895 Professor Popoff[5] of Cronstadt, Russia, constructed a very sensitive filings coherer, one form of which was used in some surveying experiments by the Russian govern-

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1. See Guthe " Coherer action " *Transactions of the International Electrical Congress*, St. Louis, 1904, page 242. *Munck. Poggendorff Ann.* 1838, *Vol.* 43, *p.* 193.

2. Branley, *Comtes Rendues*, 1890, page 785, and 1891, page 90.

3. Minchen, *Proceedings Physical Society*, London 1893, page 455.

4. Sir O. J. Lodge, " The Work of Hertz ", *Proceedings Royal Institution*, June 1, 1904, Vol. 14, page 321.

5. *Journal Russian Physico-Chemical Society*, Vol.27. April 25,1895,

ment.[1] consisting of iron filings suspended by a magnet and resting upon a metallic plate or cup. Other forms consisted of filings in glass tubes with platinum electrodes. He used early in 1895, the automatic tapping back mechanism, and substituted for the galvanometer an ordinary telegraphic relay. He operated this apparatus at a distance by means of a large Hertzian radiator. One terminal of his coherer was connected to a conductor fastened to a mast about 30 ft. high on the top of the Institute building and the other terminal of the coherer was grounded.

At the conclusion of his paper, which is dated December, 1895, Popoff made the following statement "In conclusion I can express the hope that my apparatus, with further improvements of same, may be adapted to the transmission of signals at a distance by the aid of quick electric vibrations, as soon as the source of such vibrations, possessing sufficient energy, will be found."

Among other experimenters who were working on this subject at the same time may be mentioned Captain Jackson of the British Navy, and Mr. A. C. Brown.

Marconi, on June 2, 1896, filed a provisional specification[2] showing two forms of apparatus, one similar to Lodge's 1894 apparatus using ungrounded aerials for both sending and receiving and the other for use "when transmitting through the earth or water" substantially identical with Lodge's 1894 and Popoff's 1895 apparatus, with tapper back etc., and the receiving antenna only being grounded.

Soon after, in July 1896, Marconi arrived in England and made a number of experiments for the English Post Office at Salisbury Plain and elsewhere, using ungrounded aerials and parabolic reflectors and succeeded in reaching nearly two miles.

On March 2, 1897, Marconi filed the complete specification in which was included a statement that the transmitting antenna also could be grounded.

Lodge filed a provisional specification[3] showing radiating spheres but no antenna on May 10, 1897. The complete specification filed on Feb. 5, 1898, shows as one form both antennæ

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1. A. S. Popoff, "Apparatus for detection and registration of electrical vibrations", *Journal Russian Physico-Chemical Society*, Vol. 28, Dec. 1895.

2. Marconi, Great Britain patent, 12,039, 1896.

3. Lodge, Great Britain, patent, 11,575, 1897.

grounded and also the use of an inductance wound in the form of a coil for the purpose of diminishing the rate of damping of the waves.

So far as is known little work was done in America during this period. The writer made some experiments in 1896 and in conjunction with two of his students, Messrs. Bennett and Bradshaw, did considerable work on receivers of various type in the fall of 1896 and spring of 1897, the results of which were incorporated in a thesis.[1]

3. 1898. *Return to First Principles and Foundation, on lines Antithetical to Old, of New or Sustained Oscillation non-microphonic Receiver Method.* Up to the year 1898, as may be seen from the above, the development of wireless telegraphy had proceeded along a single line. In that year, however, an entirely new method of wireless telegraphy was developed, characterized by a return to first principles, the abandonment of the previously used methods and by the introduction of methods in almost every respect their exact antitheses.

While the coherer is of more or less interest theoretically it is not adapted for use for telegraphic purposes. Responding as it does to voltage rises above a certain limit it does not discriminate between impulses of different characters, and is therefore peculiarly susceptible to interfering signals and atmospheric disturbances, and the operation of coherer systems cannot be guaranteed during the summer months or in the tropics. Roughly speaking a coherer acts by starting an arc and making a short-circuit on the line every time a signal is received, which short-circuit persists until it is broken by a blow from an additional mechanism, and such a method of operation is obviously far from practical. In addition it is practically impossible to obtain sharp tuning in a local circuit containing a coherer; its action is always more or less erratic, its electrostatic capacity variable, and it is insensitive.

At the sending end the energy which can be liberated by the discharge of an antenna is limited and in the form used prior to 1897 the dampening is so great that there are only a few oscillations per spark.

Lodge[2] by placing a coil of large inductance in the antenna throttled down the amount of energy radiated per oscillation and so obtained with the same limited amount of energy derived from the charged antenna, an increase in the time of damping.

1. Western University of Pennsylvania, May, 1897.

2. Lodge, Great Britian, patent 11,575, 1897.

Braun[1] patented the method of using a local oscillatory circuit connected to an antenna, the local oscillatory circuit having a much longer period than the natural period of the antenna and of a different order of magnitude. Such a system, however, does not radiate energy appreciably, and produces a damped wave.

This dampening and the limited amount of energy obtainable by charging and discharging the antenna operates to prevent sharp tuning and working over long distances.

The coherer is well adapted for working with damped waves, but the coherer-damped wave method can never be developed into a practical telegraph system. It is a question whether the invention of the coherer has not been on the whole a misfortune as tending to lead the development of the art astray into impracticable and futile lines and thereby retarding the development of a really practical system.

The fact that no coherer-damped wave system could ever be developed into a practically operative telegraph system, and the fact that it was necessary to return to first principles and initiate a new line of development along engineering rather than laboratory lines was perceived in America in 1898[2] and a new method was advised which may be called the Sustained Oscillation-non-microphonic Receiver method as opposed to the Damped Oscillation-coherer method previously used.

4. *Fundamental Differences between the Old and New Wireless Schools.* The differences between the two methods are shown in tabulated form:

	Damped Oscillation-coherer Method		Sustained Oscillation-non-microphonic Method.
A1:	Damped oscillations are produced at the sending end.	A1:	Sustained oscillations are produced at the sending end.
2:	The energy transmitted is obtained by charging the antenna and discharging it.	2:	The energy transmitted is derived from a local source and fed into the antenna.
3:	A spark gap is used for producing the oscillations.	3:	An arc or high frequency dynamo is generally used for producing the oscillations.

1. Braun, German patent 11,578, Oct. 14, 1898.

2. *Electrical World*, July 29, Aug. 12, Sept. 16, 1899 and *Proceedings American Institute of Electrical Engineers*, Nov. 1899, p. 635 and Nov. 20, 1906, p. 731.

B1:	Imperfect or microphonic contact receivers are used.	B1:	Non-microphonic contact receivers are used.
2:	The action of the receiver depends upon the voltage rise and is independent of the amount of energy received.	2:	The receiver response is determined by the integral amount of energy received.
3:	An open tuned circuit is used for receiving.	3:	A closed tuned circuit is used for receiving.
4:	The receiving circuit is tuned to the wave frequency only.	4:	The receiving circuit may be tuned to a group frequency as well as to the wave frequency.
C1:	In transmitting messages the production of the electromagnetic waves is intermittent.	C1:	The waves are preferably generated continuously and the transmission accomplished by changing the character of the wave.
2:	The wave energy flux is intermittent.	2:	The wave energy flux is constant.
3:	A high voltage is used.	3:	A low voltage is used.
4:	Comparatively short wave lengths are used.	4:	Comparatively long wave lengths are used.
5:	The signals consist of dots and dashes, whose interpretation is fixed.	5:	The signals may consist of dots only, whose interpretation depends on the station sending and receiving.
D1:	Antennæ are used adapted, roughly speaking, to utilize the electrostatic component of the electromagnetic waves.	D1:	The antennæ are preferably arranged so as to utilize the other component of the electromagnetic waves instead of the electrostatic component.

The history of these two antithetical lines of development will be treated of separately.

5. *Period* 1898–1902 A. *Development and Perfecting of Sustained Oscillation-non-microphonic Receiver Method* (a) *The current-operated receiver.* The first essential for the development of the system was, of course, a quantitatively responsive receiver. Several forms of this were tried including the modification of the Boys' radio-micrometer (consisting of a light thermo couple suspended in the field of a permanent magnet

and heated by radiation from a wire which in turn was heated by the current to be detected) described by the writer at the Columbus meeting of the American Association in 1897.[1] This was abandoned in favor of Professor Elihu Thomson's alternating-current galvanometer[2] suitably modified for telegraphic work.[3]

Among other forms of current-operated receiver may be mentioned the following.

The *Hot-wire Barretter*,[4] consisting of a minute platinum wire a few hundred thousandths of an inch in diameter and approximately a hundredth of an inch in length. The term "barretter" was coined for this device for the reason that it differs essentially from the bolometer of Langley in that it is arranged to be affected by external sources of radiant heat as little as possible instead of as much as possible, and, to have an extremely small specific heat, an object not sought in the case of the bolometer.

The *Liquid Barretter*[5] in which the change of resistance is effected by heating a liquid, the concentration of path being obtained by means of a fine platinum wire point. Some question has been raised as to the theory of operation of this device but I think there is no question but that the effect is due to heat, though what per cent. of the effect is due to change in ohmic conductivity by heat and what per cent. is due to depolarization by heat is still, as originally stated by the writer,[6] uncertain. The facts that the device operates practically equally well irrespective of which terminal is connected to the local battery, and that the effect varies as the square of the alternating current (as a heat operated device should do) instead of directly with the alternating current as a rectifier would do, and that depolarization is produced by the heat, have been confirmed by Dr. L. W. Austin.[7] The writer has experimentally determined the fact that though the electrical impulses may have a duration of less than a millionth part of a second the change in resistance persists for approximately the ten thousandth part of a second, which would seem to show conclusively that the action is not a *direct* effect of the waves.

1. *Electrician*, June 24, 1904.
2. Elihu Thomson, U. S. patent 363,185, Jan. 26, 1887.
3. U. S. patents 706,736 and 706,737, Dec. 15, 1899.
4. U. S. patent 706,744, June 6, 1902.
5. U. S. patent 727,331, April 9, 1903.
6. *Ibid.*
7. Austin, *Bulletin of the Bureau of Standards*, Vol. 2 No. 2.

The term electrolytic receiver has sometimes been applied to the liquid barretter. This is objectionable, as there are a number of electrolytic receivers. For example, the Neughschwender-Schaefer[1] receiver, in which a number of microscopic filaments are produced between two terminals by electrolysis, which filaments are ruptured by the wave produced oscillations, thus increasing the resistance; also the liquid coherer of Captain Ferrie, described by him as follows:[2]

> The same effect of self-decohering coherence has been determined for a contact of a metallic wire and a liquid conductor, acidulated water, contained in a glass tube of small diameter, and placed under the same conditions as the preceding. Always, the sensitiveness of this contact is very notably inferior to that obtained in the experiments disclosed above. The maximum sensitiveness was obtained when the resistance of the imperfect contact was about 2000 ohms and when the extremity of the metal wire scarcely grazed the meniscus of the liquid. The results obtained were better with a copper wire, attacked by the acidulated water, than with a platinum wire.

which probably acts through a chemical effect producing a thin film of gas and has never come into use, doubtless because, as Captain Ferrie points out, it is even less sensitive than the Marconi coherer. Also the rectifier of Pupin[3] in which the terminals are placed so closely together that practically no energy is absorbed in the receiver, in order that the rectified energy may be utilized outside in the external circuit, in opposition to the liquid barretter, where the position of the terminals is such that all the received wave energy is absorbed in the barretter for the purpose of producing a secondary effect, and so influencing the current in a shunted local circuit.

(b) *Methods of Obtaining Sustained Oscillations.* 1. *Spark-gap and Local Oscillatory or "tank" Circuit.* Professor Elihu Thomson discovered that by using a transformer without an iron core (the well known Elihu Thomson air-core transformer, later used by Tesla and others), and a spark-gap and condenser in the primary circuit and with the secondary circuit suitably tuned great resonant rises of potential could be obtained. In 1892 he constructed such a transformer giving discharges 64 inches long.[4]

The same method was later used by Tesla[5] in his experimental

1. Neughschwender German Patent 107843, Dec. 13, 1898, and Schaefer British Patent 6002, 1899.
2. Blondel, *L'Eclairage Electrique*, Sept. 29, 1900.
3. Pupin, U. S. Patent 713,044, January 4, 1898.
4. *Electrical World*, Feb. 20 and 27, 1892.
5. U. S. patent 645,516, Sept. 2, 1897.

researches and in his attempt to carry out Loomis'[1] method of transmitting a current through a hypothetical conducting stratum in the upper regions of the atmosphere.

The device, suitably modified for wireless telegraphic purposes, so as to give instead of a continuously cumulative rise of potential an initial rise of potential followed by a gradual feeding in of the energy from the local circuit to supply the energy lost from radiation, was made use of in 1898 for the purpose of producing prolonged trains of sustained waves.

Various types of connection between the antenna and the local oscillatory circuit were tested but it was found that the most efficient results were obtained by connecting the local circuit directly across the spark-gap.[2]

The results of some comparative tests are here given. The figures in the column " A " are for the local circuit connected directly to the terminals of the spark-gap, those in column " B " are for an auto-transformer, those in column " C " for a loose coupled primary and secondary.

	A	B	C
Frequency........	212,000	212,000	212,000
Tank capacity.....	0.072 m.f.	0.072 m.f.	0.072 m.f.
Kilowatt output dynamo...........	30	30	30
Tank current......	400 amperes	370 amperes	300 amperes
Antenna current...	48.5	46.	48.

The large station at Brant Rock is operated with the local circuit directly connected across the spark-gap, partly because the efficiency is somewhat greater, but also on account of the great simplification of connections and the fact that the degree of sustainment of the wave train may be adjusted very simply, if desired, by sliding the lower terminal of the antenna along a few inches of the lead of the local oscillatory circuit.

Cooper Hewitt[3] in 1902 used a modification of his mercury lamp to obtain intermittent discharges each followed by a train of high frequency oscillations.

2. *Arc methods.* The worker with high frequency oscillatory currents will soon discover that we are indebted to the genius of Professor Elihu Thomson for practically every device of any importance in this art.

1. Loomis, U. S. patent, 129,971, July 30, 1872.
2. U. S. patents 706,735 and 706,736. Dec. 15, 1899.
3. Cooper Hewitt, U. S. patent 780,999, April 25, 1902.

The method of producing high frequency oscillations from an arc and continuous current was discovered by him in 1892.[1] Fig. 1, taken from his patent, shows the general form of his arrangement. If the directions given in the specification are followed no difficulty will be met with in obtaining frequencies as high as 50,000 per second.

Between 1900 and 1902 some experiments were carried out with the Elihu Thomson arc as a source of high frequency oscillations for wireless telegraphy and telephony.

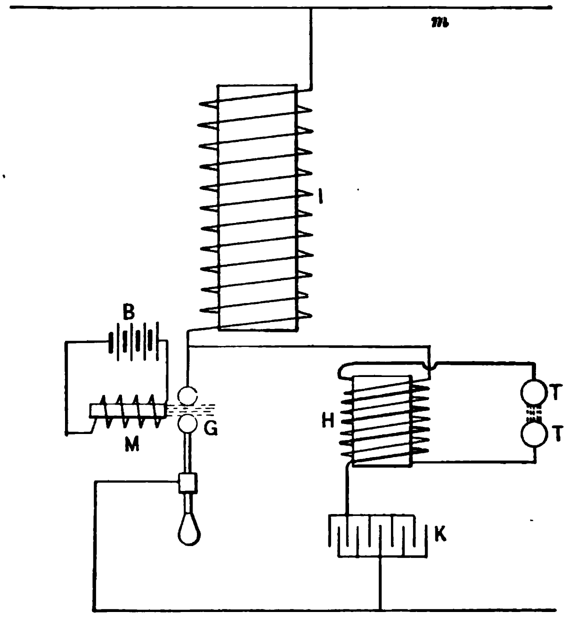

Fig.1

Some difficulties were found, for example the arc could not be started and stopped as quickly as was necessary for telegraphic purposes and the intensity of the oscillations and their frequency varied considerably. These were overcome by making some minor improvements, for example the difficulty in sending was overcome by permitting the arc to run continuously and using the key to change the electrical constants of the circuits.[2] The difficulty in keeping the intensity and frequency constant was

1. Elihu Thomson U. S. patent 500,630, July 18, 1892.

2. U. S. patents 706,742, July 6, 1902, 706,747, Sept. 28, 1901, 727,330, March 21, 1903, 730,753, April 9, 1903.

overcome by substituting resistance for a portion of the inductance, and also by using the arc under pressure.[1]

Tests made by Dr. Austin[2] show that with this method frequencies as high as 3,000,000 per second and efficiencies as high as 60% can be obtained together with an absolutely steady[3] generation of the high frequency currents and an absence of harmonic frequencies.

3. *High frequency alternator.* The first high frequency alternator was built by Professor Elihu Thomson in 1889. And it[4] was while experimenting with it in 1900 that Dr. Tatum made his very interesting discovery that high frequency currents of large amperage could be passed through the body without injury.[5]

FIG. 2

From 1898 to 1900 numerous experiments were made on antennæ of large capacity and it was found that instead of using sheets of solid metal or wire netting, single wires could be placed at a considerable fraction of the wave-length apart and yet give practically the same capacity effect as if the space between them were filled with solid conductors.

From other investigations on the variation of radiation with

1. *Ibid* and U. S. patent 706,741.
2. Austin, *Bulletin of the Bureau of Standards*, Vol. 3, No. 2.
3. Austin assumed from the figure he obtained for the dampening, that the oscillations were not continuous; but the method used for determining the dampening is not applicable to this case, and a comparison of the currents and voltages with the frequencies given in Austin's experiments, shows that these oscillations must have been continuous.
4. Thomson, *Elec.Engineer*, July 30,1890 and *London Elec.*,Sept.12,1890.
5. Thomson, *Elec. Engineer*, March 11, 1891.

frequency the result was arrived at that it should be possible to construct an alternating-current dynamo of sufficiently high frequency and output to give ample radiation for wireless telegraphic purposes.[1]

In 1900 a large American electrical manufacturing company kindly consented to take up the construction of such a dynamo. As a preliminary, a dynamo of 1 kw. output and 10,000 cycles (shown in Fig. 2) was built in 1902. By the summer of 1906 many of the difficulties had been overcome and a machine giving 50,000 cycles was installed at the Brant Rock station. Various improvements were made by the writer's assistants, and in the fall of 1906 the dynamo was working regularly at 75,000 cycles, with an output of half a kilowatt and was being used for telephoning to Plymouth, a distance of approximately 11 miles. In the following year machines were constructed having a frequency of 100,000 cycles per second and outputs of 1 and 2 kilowatts.

The credit for the development of this machine is due to Messrs. Steinmetz, Haskins, Alexanderson, Dempster, and Geisenhoner and also to the writer's assistants, Messrs. Stein and Mansbendel.

(*c*) *Closed tuned circuits.* In 1898 the open tuned circuits originally used were discarded for closed tuned circuits[2] and it was discovered that valuable selective effects could be obtained by placing the condenser in shunt to the inductance instead of in series with it.[3]

(*d*) *Combination of wave and group tuning.* The fact that if selectivity is obtained solely by tuning to wave frequencies, the number of stations is limited, was appreciated at an early date. In 1900[4] a new method was developed, the stations being tuned both to the wave frequency and to an independent or group frequency, so that stations might obtain selectivity by varying either the wave or the group frequency and thus have at their disposal a virtually unlimited number of combinations and be practically free from atmospheric disturbances. Fig. 3 shows a type of group tuner.

(*b*) *Further development of damped wave-coherer method.* Marconi by 1898 had carried the development of the filings coherer to its maximum point.

1. U. S. patent 706,737, May 29, 1901.
2. U. S. patents 706,735 and 706,736, Dec. 15, 1899.
3. *Ibid.*
4. U. S. patents 727,325, June 2, 1900, and 727,330 March 21, 1903.

Lodge in 1897[1] had disclosed the open secondary circuit for receiving.

Marconi in 1898[2] greatly improved this by adjusting the length of the secondary so as to tune it, and by the aid of this improvement was enabled to telegraph a distance of 35 miles[3] in October, 1899.

Lodge in 1902[4] invented what is perhaps the most perfect form of coherer, consisting of a thin steel disc dipping in oil

FIG. 3.

covered mercury and automatically decohered by being kept in continuous rotation.

A number of self-restoring coherers of which the Brown[5]

1. Lodge, Great Britain patent, 11,575, May 10, 1897.
2. Marconi, Great Britain patent, 12,326, June 1, 1898.
3. Official report U. S. Navy of test U. S. S. Massachusetts, Oct. 1899.
4. Lodge, Muirhead and Robinson, Great Britain patent, 13,521, June 14, 1902.
5. Brown and Neilson, Great Britain patent, 28,955, Dec. 17, 1896.

carbon coherer may be taken as a type, including the mercury carbon coherer of Solari, came into more or less extended use, and also modifications of the imperfect contact receiver of Neugschwender.[1]

The small progress made along these lines is to be explained by the fact that the damped wave-coherer system is essentially and fundamentally incapable of development into a practical system.

Period 1902-1908—*Later Developments*. Progress in Europe since 1902 has been marked by the gradual abandonment of the elements of the damped wave-coherer system and the substitution of elements of the sustained wave non-microphonic contact type.

In 1900[2] Marconi substituted for the plain aerial an aerial with the writer's tuned local circuit or tank circuit for sending, thus obtaining a considerable increase in range of transmission.

In 1902, Marconi invented a very ingenious form of current operated receiver, called the magnetic detector[3], and with this combination achieved some very remarkable results.

In 1905 Professor Fleming[4] invented a very efficient detector based on the " Edison effect " in incandescent lamps, and the observations of Elster and Geitel[5] on the rectifying effect of such an arrangement on Hertzian oscillations.

Virtually nothing was done in Europe in the way of producing sustained oscillations by the arc or high frequency method until recently, possibly because of Duddell's erroneous statement[6] to the effect that frequencies much above 10,000 could not be obtained by the Elihu Thomson arc method, and Fleming's statement[7] that an abrupt impulse was necessary and that high frequency currents, even if of sufficient frequency, could not produce radiation.

In 1903 Poulsen[8] invented an interesting modification of the Elihu Thomson arc, which consists in forming the arc in hydro-

1. A. Neugschwender, *Wied. Ann. der Physik*, 1899, vol. 67, p. 430. Schafer, British patent, 6,002, 1899.
2. Marconi, Great Britain, patent, 7,777, Apr. 26, 1900.
3. Marconi, Great Britain, patent, 10,245, 1902.
4. Fleming, *Proceedings Royal Society London*, 1905, Vol. 74.
5. Elster and Geitel, *Wied. Ann der Physic*, Vol. 52, page 433.
6. Duddell, *The Electrician*, 1903, Vol. LI, page 902.
7. Fleming, *Proceedings of the International Congress, St. Louis*, 1904, Vol. 3, page 603.
8. Poulsen U. S. patent 789,449, June 19, 1903.

gen instead of in air or compressed gas as previously done. This modification is not, however, so efficient as the older methods and gives oscillations varying in amplitude and intensity and accompanied by strong harmonics,[1] but I have considered it worth mentioning on account of the amount of interest it appears to have excited in Europe.

Some very important and interesting papers on electrical oscillations were published during these years by Oberbeck,[2] Wien,[3] Drude,[4] and Bjerknes.[5]

FIG 4.

In America the development of the sustained oscillation non-microphonic system has proceeded steadily and it may now be said to have reached the stage of commercial practicability. On account of the amount of work which has been done it is impossible to refer to more than a few of the recent advances.

1. Austin, *Bulletin of the Bureau of Standards*, Vol. 3 No. 2.
2. Oberbeck Wied. *Ann. der Physik*, Vol. 55, 1895.
3. *Wied Ann. der Physik* Vol. 8, 1902.
4. Drude *Ann. der Physik*, Vol. 13, 1904.
5. Bjerknes, *Ann. der Physik*, Vol. 44, 1891, and Vol. 47, 1892.

The following are some of the later types of detectors:

The *frictional receiver*,[1] in which the waves produce a change of friction between two moving surfaces and so cause an indication.

The *heterodyne receiver*,[2] in which a local field of force actuated by a continuous source of high frequency oscillations interacts with a field produced by the received oscillations and creates beats of an audible frequency.

The so called *thermoelectric receivers* of Austin,[3] Pickard[4] and Dunwoody.[5]

The "*audion*" *of deForest*,[6] a very interesting and sensitive

Fig. 5.

device, which though superficially resembling Professor Fleming's rectifier appears to act on an entirely different principle.

The *Cooper Hewitt mercury receiver*, about which little is known but which appears to be very sensitive.

The following are some of the later methods of producing sustained oscillations:

1. U. S. application, 251,538, March 22, 1905.
2. U. S. application, 271,539, June 28, 1905.
3. Austin, U. S. application, 319,241, May 29, 1906.
4. Pickard, U. S. application, 342,465, Nov. 8, 1906.
5. Dunwoody, patent, 837,616, March 23, 1906.
6. deForest, U. S. patent, 836,070, Jan. 18, 1906.

The *substitution of a number of arcs in series having terminals of large heat capacity* in place of the single arc in the arc method.[1]

The *use of regulating or " fly-wheel " circuits* in connection with the arc method.[2]

The *method of producing oscillations* shown in Fig. 4 by using two arcs and throwing the discharge from one side to the other alternately at a frequency regulated by the constants of the electric circuit.[3]

The *condenser dynamo*[4] which consists of two radially slotted discs separated by a mica diaphragm, charged by a continuous current source of potential, and rotating in opposite directions.

Two-phase high frequency dynamo method.[5]

Commutator method.[6] In this method the high frequency is produced by means of a ball rotating at high speed on the interior surface of a commutator. Shown in Fig. 5.

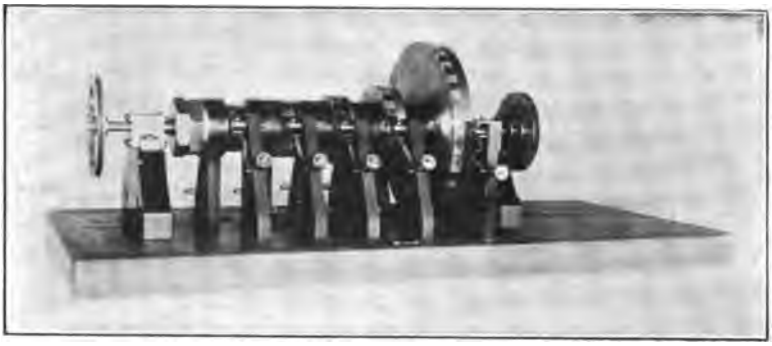

FIG. 6.

The *helium arc method*[7] in which the arc is produced in helium or argon or similar gases.

The *critical pressure method*[8] in which the electrodes extend within a certain critical distance, depending upon the pressure used, so that the discharge always passes at the same voltage irrespective of the distance between the electrodes.

1. U. S. application, 291,737, Dec. 14, 1905.
2. *Ibid.*
3. *Ibid.*
4. U. S. application, 291,739, Dec. 14, 1905.
5. U. S. patent, 793,649, March 30, 1905.
6. U. S. application, 316,521, May 12, 1906.
7. U. S. application, 351,560, Jan. 7, 1907.
8. U. S. application, 355,787, Feb. 4, 1907.

Methods of Signaling. Continuous production of waves but changing constants of sending circuit.[1]

The *inverted method* of sending and the method of signaling by sending dots, the interpretation of which is determined by similar commutators at the sending and receiving stations.

Duplex and Multiplex Methods. A considerable number of these have been worked out, mostly operating either by balance methods[2] or commutators.[3] It is impossible to discuss all the various improvements, such for example as the method of indicating the busy and free state of a station, the methods of sending and receiving in one direction, the various types of aerials used for receiving the other components of the electromagnetic waves besides the electrostatic component, etc.

Fig. 7.

Fig. 6 shows the harmonic interrupter for determining the variation of intensity with change of note.

Fig. 7 shows a type of receiver described in U. S. Patent 706,747, in which the telephone diaphram is formed of thin copper and repelled by a fixed coil having a resistance of about 16 ohms. The principle of this receiver was discovered by Professor Elihu Thomson. It has been used for wireless telephony for a distance of 11 miles with fairly satisfactory results.

Fig. 8 shows a transformer used in the transmitting circuit. The number of primary and secondary turns can be altered continuously, and also the degree of coupling. The wire is

1. U. S. patents 706,747, Sept. 28, 1901; 706,742, June 6, 1902; 727,747, March 21, 1903.

2. U. S. application, 366,528, April 5, 1907.

3. U. S. patent, 793,652, April 6, 1905.

wound off from an insulating cylinder onto a cylinder of copper, and the cylinder of copper, forming a closed circuit secondary of the transformer, annuls the inductance of that portion of the wire wound upon the copper cylinder.

Fig. 9 shows an apparatus for determining the best shape of coil for use with the heterodyne receiver.

Fig. 10 shows a group-tuned call; that is, a vibration galvanometer which operates a selenium cell and rings a bell when a call is received.

C. Theory of Wireless Telephony

For wireless telephony three things are necessary:

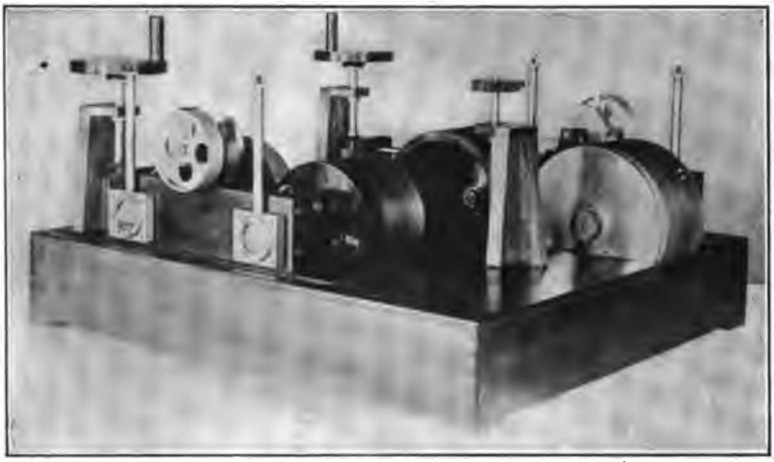

Fig. 8.

1. Means for radiating a stream of electrical waves sufficiently continuous to transmit the upper harmonics on which the quality of the talking depends.
2. Means for modulating this stream of waves in accordance with the sound waves.
3. A continuously responsive receiver giving indications proportional to the energy received, and capable of responding with sufficient rapidity to the speech harmonics.

Work on the wireless telephone was commenced before a satisfactory means was discovered for producing sustained oscillations.

To ascertain the number of sparks per second which was necessary to determine articulate speech, a phonograph cylinder was taken and grooves were cut in it longitudinally. It was found in this way that practical transmission could be accomplished with 10,000 breaks per second. It is believed now that this number is unnecessarily high, possibly owing to the fact that it was impossible to cut the grooves on the cylinder without producing ridges. The lower limit may be fixed in another way.

Electrical circuits met with in actual working have resistance, self inductance capacity, and leakance. Heaviside gave the differential equations for the pressure and current over such circuits when alternating voltages were applied, but no method of solution being known the mathematical treatment of such

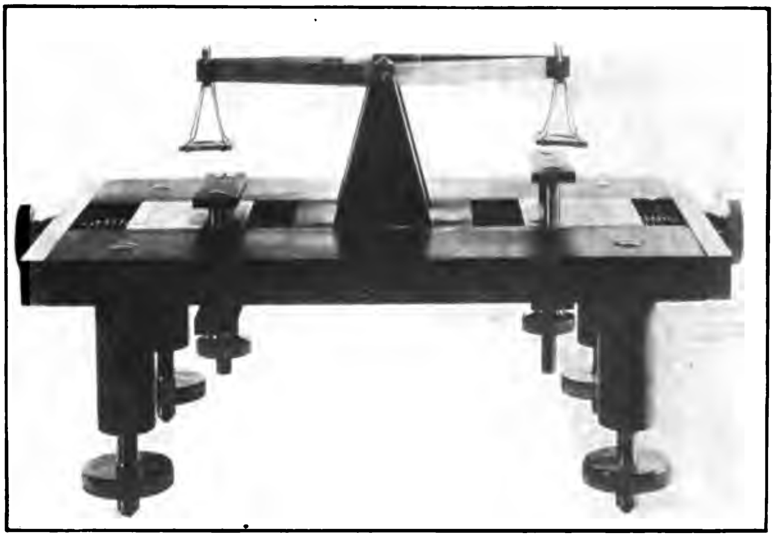

Fig. 9.

circuits was restricted to cases where one of the constants was neglected, until Dr. A. E. Kennelly in a masterly series of papers gave the complete solution.

The results were immediately found applicable to a great variety of problems, such as the transmission of signals through cables and of telephonic speech through various types of circuits.

In this way Dr. Kennelly[1] by comparing the results obtained by Dr. Hammond V. Hayes[2] in practical telephonic transmission

1. Kennelly, "Distribution of Pressure and Current over Alternating Current Circuits", *Harvard Engineering Journal*, 1906, page 43.

2. Hayes, "Loaded Telephone Lines in Practice", *Transactions International Electrical Congress*, St. Louis, Vol. 3.

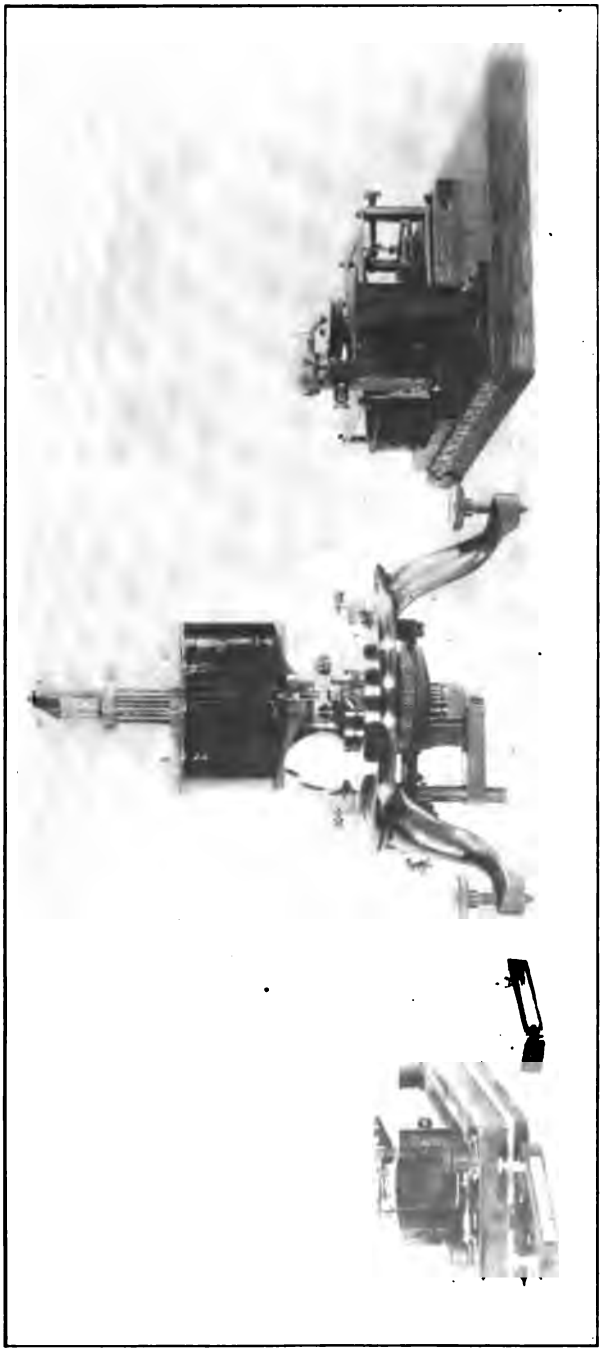

Fig. 10.

over loaded lines with the theoretical values of the current for different harmonics showed that harmonics above 2,000 per second could be neglected for telephonic transmission.

The writer has never succeeded in obtaining good talking with such a low frequency, but under favorable conditions fairly satisfactory speech may be obtained with 5,000 interruptions per second. For really good transmission, however, the radiation must be practically continuous, for if the spark frequency is less than 20,000 per second there is a disagreeable high pitch note in the telephone, not noticeable perhaps at first but apt to become annoying with use. The most satisfactory way is, of course, to use a source of sustained oscillations.

It fortunately happens that for wireless telephonic purposes it is inadvisable to use a wave frequency of less than 25,000 per second, on account of the difficulty in radiating energy with low frequencies.

The receiver must, of course, be continuously responsive. If, for example, it had to be tapped back in order to restore it to the responsive condition, speech could not be transmitted.

It must also give indications proportional to the energy received or the character of the speech will be distorted.

It must also respond with sufficient rapidity. If, for example, it takes a thousandth of a second to restore itself to its original resistance the receiver will obviously not record the higher harmonics. I have experimentally determined that a receiver which restores itself in the ten thousandth part of a second acts with sufficient rapidity.

D. History of the Development of Wireless Telephony

The writer has been asked on several occasions how the wireless telephone came to be invented. In November, 1899, shortly prior to the delivery of my previous paper,[1] while experimenting with the receiver shown in Fig. 3 of that paper, I made some experiments with a Wehnelt interrupter for operating the induction coil used for sending.

In the receiver mentioned the ring of a short-period Elihu Thomson oscillating current galvanometer rests on three supports, *i.e.*, two pivots and a carbon block, and a telephone receiver is in circuit with the carbon block. A storage battery being used in the receiver circuit[2] it was noticed that when the sending key

1. *Transactions American Institute Electrical Engineers*, Nov. 22, 1899.
2. U. S. patent, 706.736, December 15, 1899.

was kept down at the sending station for a long dash the peculiar wailing sound of the Wehnelt interrupter was reproduced with absolute fidelity in the receiving telephone. It at once suggested itself that by using a source with a frequency above audibility wireless telephony could be accomplished.

Professor Kintner, who was at that time assisting me in these experiments and to whose aid their success is very largely due, was kind enough to make the drawings for an interrupter to give 10,000 breaks per second. Mr. Brashear, the celebrated optician kindly consented to make up the apparatus and it was completed in January or February, 1900.

The experimental work was, however, delayed as the writer was at that time transferring his laboratory from Allegheny, Pa., to Rock Point, Md., and it was not until six months later that the stations at that point were completed and a suitable mast was erected for trying the apparatus.

The first experiments were made in the fall of 1900 with the above mentioned apparatus which was supposed to give 10,000 sparks per second but which probably gave less. Transmission over a distance of one mile was attained but the character of the speech was not good and it was accompanied by an extremely loud and disagreeable noise, due to the irregularity of the spark.

By the end of 1903 fairly satisfactory speech had been obtained by the arc method above referred to, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905 both the arc method and another method in which the 10,000 cycle alternator above referred to was employed, had been developed to such an extent that the apparatus could be used practically and sets were advertised and tendered to the U. S. Government.[1] The transmission was, however, still not absolutely perfect.

By the fall of 1906 the high frequency alternator had been brought to a practical shape and was used for telephoning from Brant Rock to Plymouth, a distance of 11 miles, and to a small fishing schooner,[2] this being the first instance in which wireless telephony was put in practical use. The transmission was perfect

1. Letter of July 8, 1905; see *The Electrician*, London, Feb. 22, 1907; also catalogue of 1904 and subsequent.

2. An amusing instance may be mentioned as illustrating the incredulity with which the wireless telephone was received. Some of the local papers having published an account of the experiments with the schooner above referred to the following appeared under the heading

and was admitted by telephone experts to be more distinct than that over wire lines, the sound of breathing and the slightest inflections of the voice being reproduced with the utmost fidelity.

As it was realized that the use of the wireless telephone would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented both for the receiving and transmitting ends and were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock, retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth and there relayed out again on another wire line. On Dec. 11, 1906, invitations were issued to a number of scientific men to witness the operation of the wireless transmission in conjunction with the wire lines.[1] A report of these tests appeared in the American Telephone Journal of Jan. 26 and Feb. 2, 1907, the editor being one of the men present.

" Current News and Notes " in the columns of a prominent technical journal, Nov. 10, 1906.

" A New Fish Story.—It is stated from Massachusetts that the wireless telephone has successfully entered into the deep sea fishing industry. For the last week experiments have been conducted by the wireless telegraph station at Brant Rock, which is equipped with a wireless telephone, with a small vessel stationed in the fleet of the South Shore fishermen, twelve miles out in Massachusetts Bay. Recently, it is asserted, the fishermen wished to learn the prices ruling in the Boston market. The operator on the wireless fitted boat called up Brant Rock and telephoned the fishermen's request. The land operator asked Boston by wire and the answer was forwarded back to the fishermen. This is a rather fishy fish story ".

The doubt expressed was, however, only natural. I remember the astonishment displayed by one of the company's new operators some months previously on placing the receiving telephone to his head while the vessel was almost out of sight of land and hearing the operator at the land station call his name and begin to talk to him.

1. Brant Rock, Mass., Dec. 11, 1906.

American Telephone Journal, 100 William St., New York City.

Dear Sirs: A limited number of invitations have been issued to witness the operation of the National Electric Signaling Co's. wireless telephone system between Brant Rock and Plymouth, Mass., over a distance of between ten and eleven miles.

The tests will be as follows:

1. Transmission of ordinary speech, and also transmission of phonographic talking and music by wireless telephone between Brant Rock and Plymouth.

2. Transmission of speech over ordinary wire line to wireless station at Brant Rock, relaying the speech there automatically by telephone relay and automatically transmitting the speech by wireless to Plymouth.

In July 1907 the range was considerably extended and speech was successfully transmitted between Brant Rock and Jamaica, Long Island, a distance of nearly 200 miles, in daylight and mostly over land,[1] the mast at Jamaica being approximately 180 ft. high.

In 1907 several European experimenters succeeded in transmitting speech wirelessly, using some of the earlier forms of the writer's arc method, and some months ago the vessels of

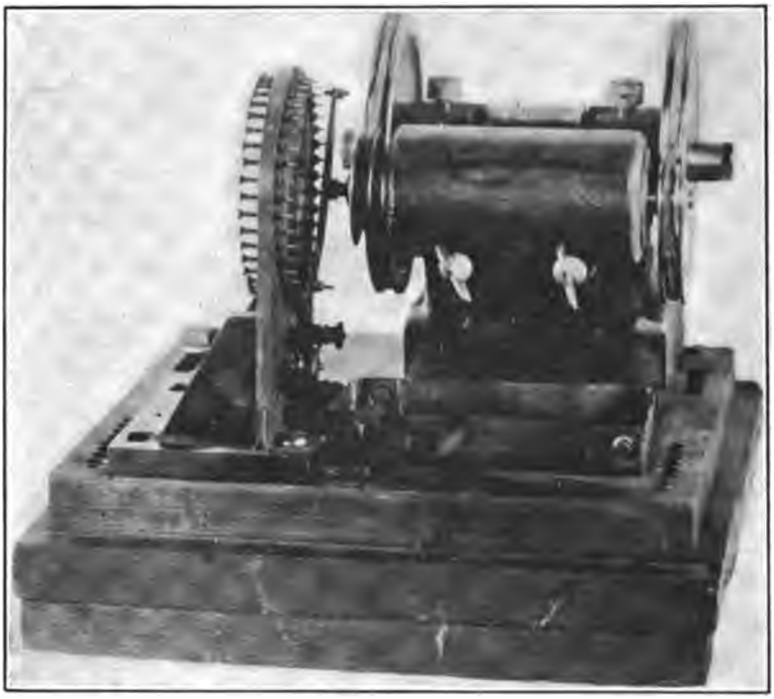

FIG. 11.

our Pacific squadron were equipped with wireless telephones, using this arc method, by another American company.

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transmitting same at Plymouth automatically directly or by telephone relay over regular wire line.

Invitations have been issued to the following gentlemen, (here follows list of some of the guests, including Dr. A. E. Kennelly, Professor Elihu Thomson, etc., and a request to the company to send a representative).

Yours very truly,
National Electric Signaling Co.

1. "Long Distance Wireless Telephony," *The Electrician*, Oct. 4, 1907.

E. Methods and Apparatus

1. *Methods and apparatus for producing the electromagnetic waves.* These have been already referred to. Fig. 11 shows a rotating spark-gap giving approximately 20,000 discharges per

Fig. 12

second. This was connected to a 5,000-volt source of direct current. The terminals are of 40% platinum-iridium. In operation the apparatus is arranged to charge a condenser to a definite potential and discharge it.

Figs. 12 and 13 show forms of apparatus for operating the arc in a gas under pressure.

The apparatus of Fig. 13 is also used for the arc in vacuum and the critical distance arc.

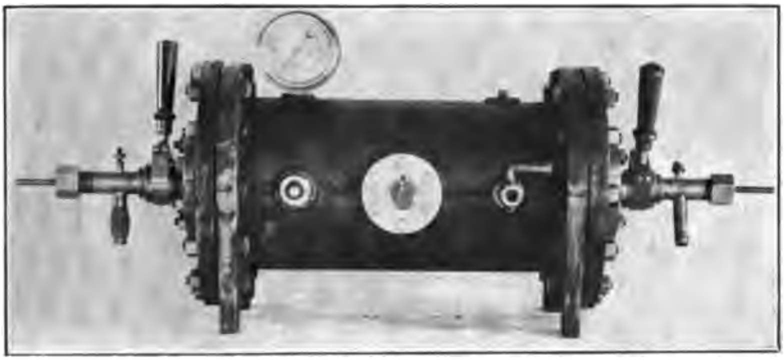


FIG. 13.

Fig. 14 shows a multiple gap with rotating electrodes, brass, amalgamated zinc and graphite being used.

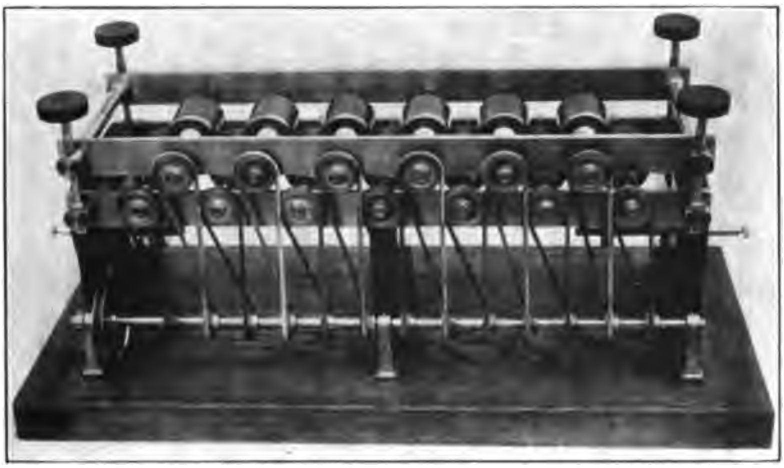


FIG. 14.

Fig. 15 shows a multiple arc gap with electrodes of different materials, the upper terminals being water cooled.

Fig. 16 shows a condenser dynamo.

Fig. 17 shows a general view of one type of high frequency alternator. It is driven by a motor and a DeLaval gear. It has been operated at 96,000 cycles per second, but is generally run at 81,700.

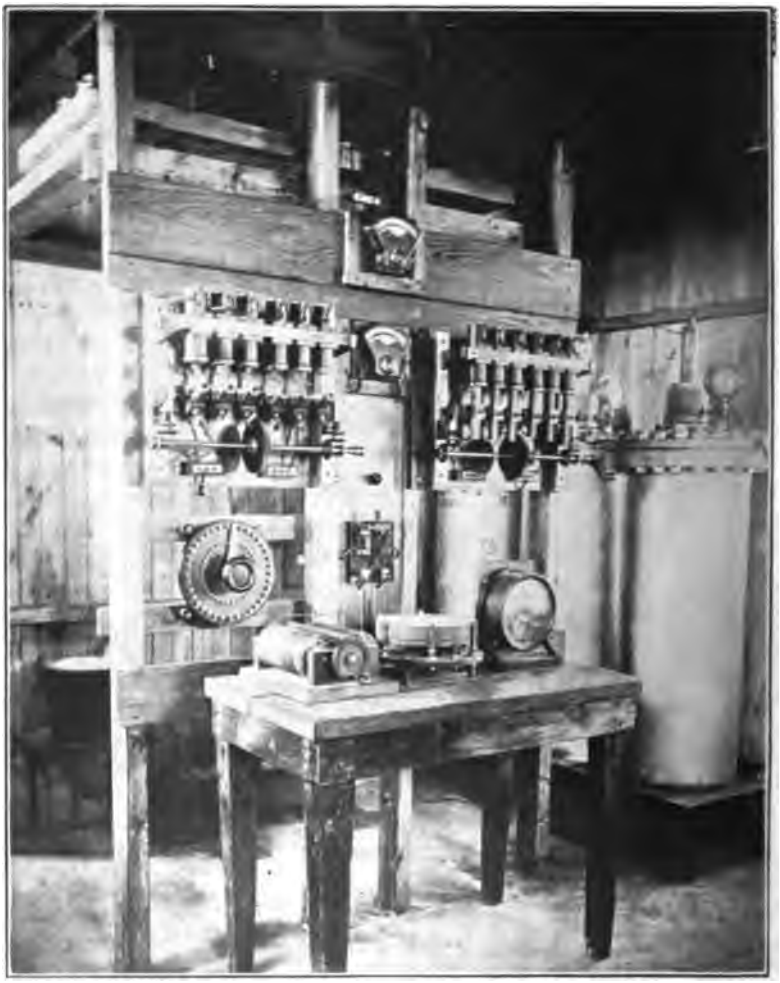


FIG. 15.

Fig. 18 shows a field disc; it is 12 inches in diameter and there are 300 slots on it.

Fig. 19 shows the armature and field coils. There are 600 armature slots each containing two turns of 13 mil wire. The

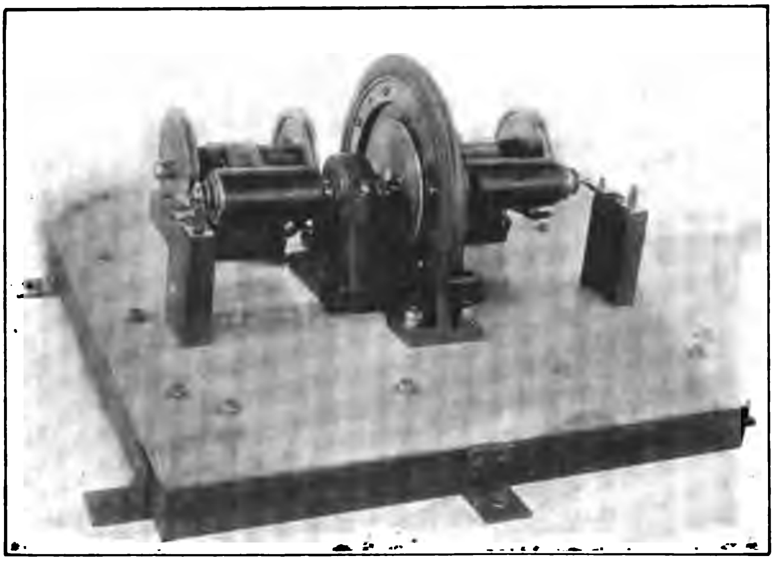


FIG. 16.

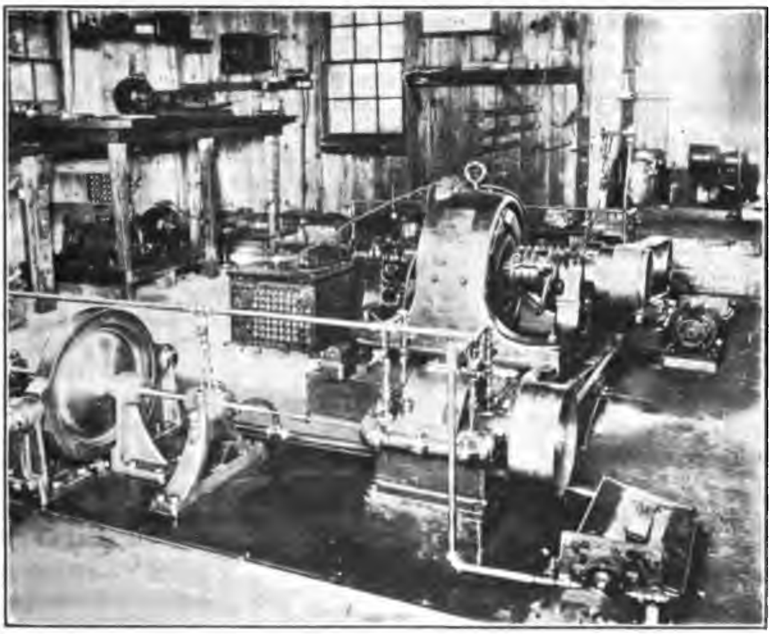


FIG. 17.

field current is 5 amperes. The resistance of the armature is 6 ohms; it gives 160 volts and about 7 or 8 amperes. Other armatures have been constructed having a resistance of 4 ohms. For some work double armatures are used giving about 270 volts. The output of the single armature machines at 81,700 cycles is approximately one kilowatt. The output of the double armature machine is approximately 2 kilowatts.

Other types of high frequency alternators are under construction. One type shown in Fig. 20 is designed for use on shipboard. The armature disc is 6 inches in diameter and two armatures are used. It is arranged to be mounted on gimbals and to be driven by a steam turbine connected to the steam pipe by flexible armored steam hose. The frequency is about 100,000 and the output about 3 kilowatts.

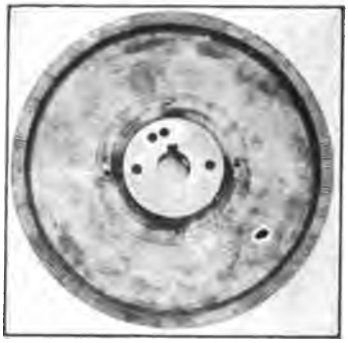


FIG. 18

Another type, which is at present being constructed by Mr. Alexanderson, to whose efforts the success of this type of generator is largely due, is designed to have an output of 10 kilowatts. Designs have been made for a generator of still larger size with a calculated output of 50 kilowatts and a frequency of 50,000. This machine is intended for transatlantic work.

For some of these machines, instead of driving by gear or steam turbine, a special two-cycle motor has been devised, to operate at a frequency of 500 cycles per second.

The high frequency alternator method is believed to possess a number of advantages over other methods, inasmuch as it is set in operation by merely opening a steam valve and has no complicated electrical apparatus or circuits of any kind. The

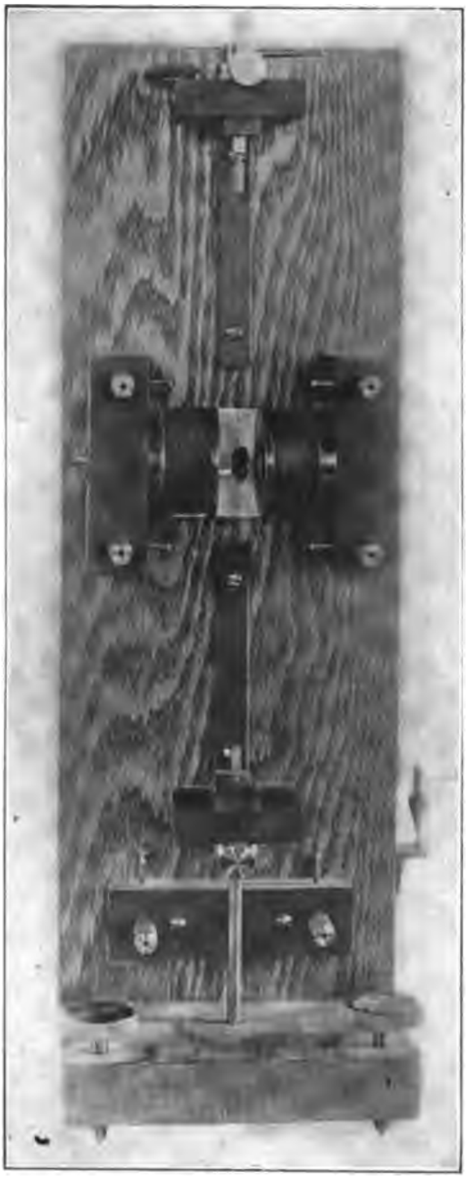


Fig. 21.

speed is regulated by the steam pressure, this being accomplished by an electrically operated reducing valve.

For measuring the frequency various speed indicators have been tried, but it has been found that the best way is to use a resonant circuit with an ammeter shown in Fig. 21 in it,[1] this being an extremely sensitive means of indicating the frequency and in addition affording a means of automatically keeping

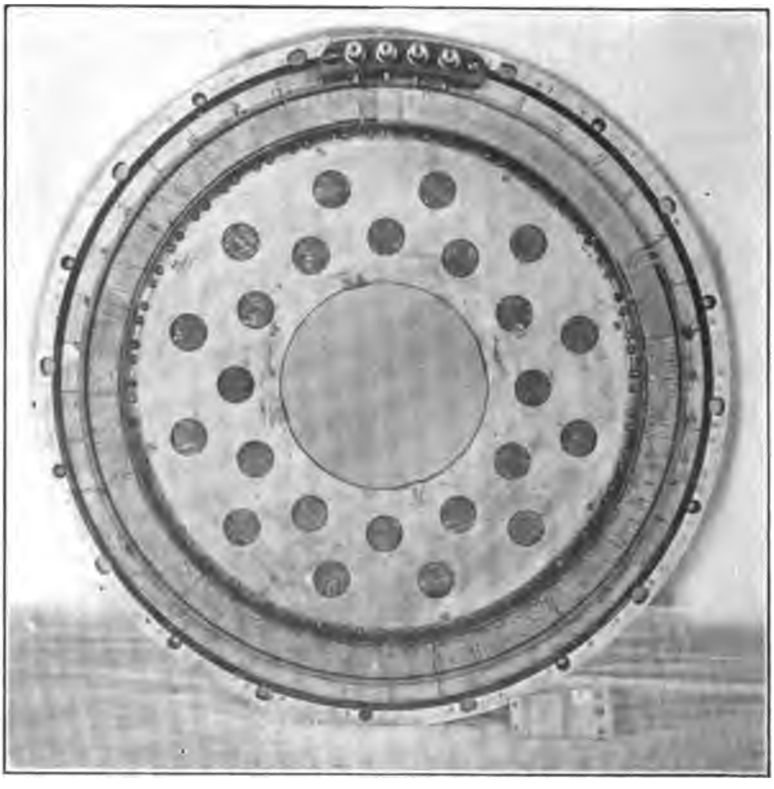


FIG. 19.

the speed constant to a small fraction of a per cent. The reducing valve is adjusted so that if left to itself the machine will run slightly above speed.[2] As soon as it reaches one-tenth of one per cent. higher than its designed speed the resonance begins to fall and a contact is opened which slightly throttles the steam. In

1. *Electrical World and Engineer*, Nov. 11, 1899.

2. Since writing the above, my attention has been called to the fact that the general method of governing by resonance was invented and patented by Kempster B. Miller, U. S. patent 559,187, Feb. 25, 1896.

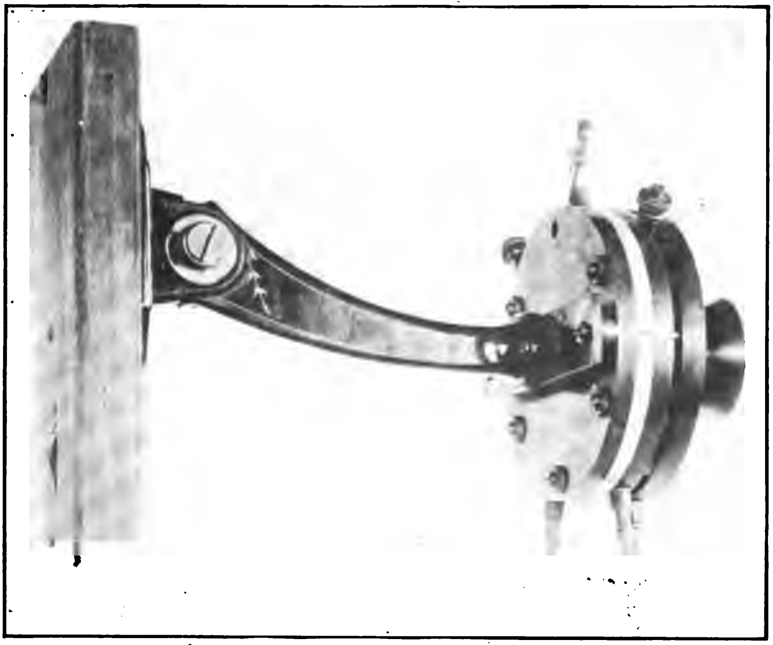


FIG. 20.

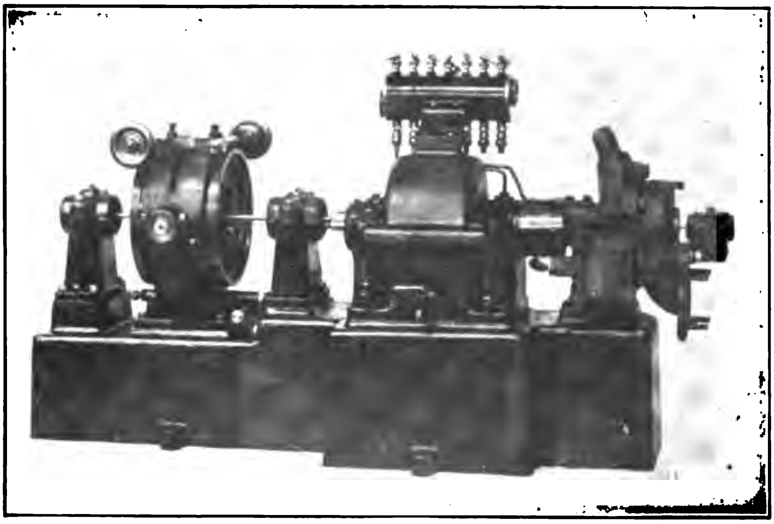


FIG. 22.

this way the frequency is kept varying between the limits of one-tenth of one per cent. above speed and one-tenth of one per cent. below speed. Where the drive is electric instead of by turbine, a storage battery is used to drive the two-phase generator and even better results may be obtained as regards regulation than with steam.

2. *Transmitters.* The types of transmitters most commonly

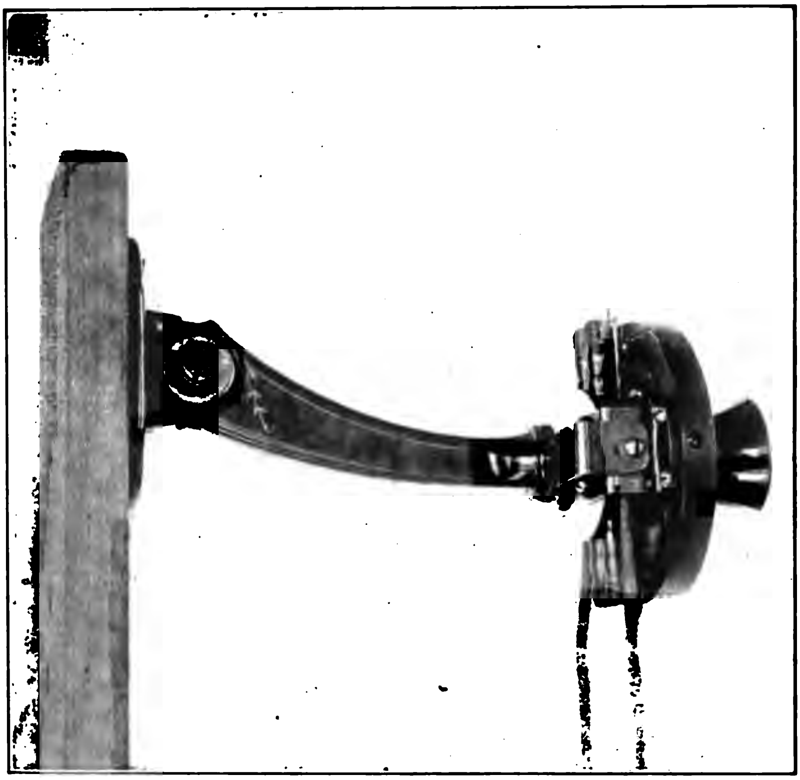


FIG. 23.

used are the carbon transmitter and static transmitter, and the carbon transmitter relay.

Fig. 22 shows the standard type of carbon transmitter.

It was found that the ordinary carbon transmitter was unsuited for wireless telephonic work on account of its inability to handle large amounts of power. A new type of transmitter was therefore designed which the writer has called the " trough "

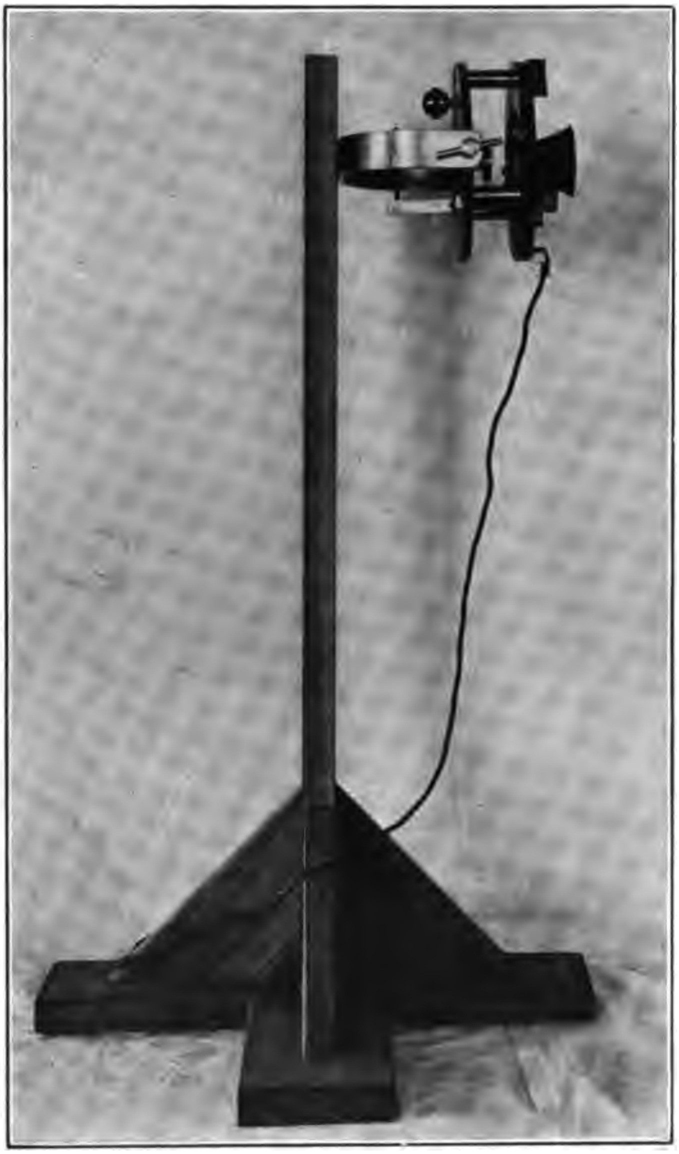


Fig. 24.

transmitter. It consists of a soapstone annulus to which are clamped two plates with platinum iridium electrodes. Through a hole in the center of one plate passes a rod, attached at one end to a diaphragm and at the other to a platinum iridium spade. The two outside electrodes are water-jacketed.

This transmitter requires no adjusting. All that is necessary is to place a teaspoonful of carbon granules in the central space. It is able to carry as much as 15 amperes continuously without the articulation falling off appreciably. It has the advantage that it never packs. The reason for this appears to be that

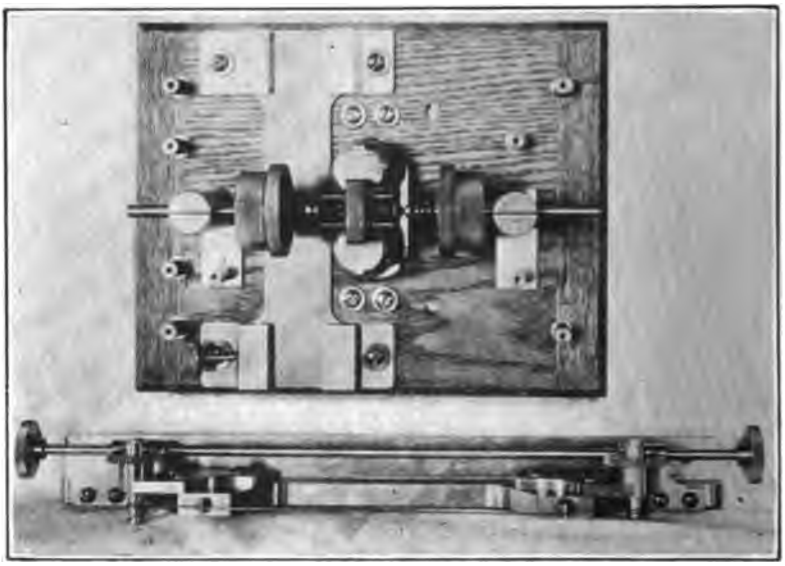


FIG. 25.

when the carbon on one side heats and expands the electrode is pushed over against the carbon on the other side. These transmitters have handled amounts of energy up to one-half horse power, and under these circumstances give remarkably clear and perfect articulation and may be left in circuit for hours at a time. Fig. 23 shows a modified form with split back.

Fig. 24 shows a type of condenser transmitter in which the vibration of the diaphragm alters the electrical capacity of the transmitter, thus throwing the circuit in and out of tune or spilling more or less energy through a leakage circuit.

Fig. 25 shows a transmitting relay for strong currents. The only thing noticeable about this is that the telephone magnet is a differential one.

Fig. 26 shows another type of transmitting relay, for amplifying very feeble currents. It will readily be understood that where a person in Albany, for example, wishes to talk to another person on board a ship off New York, the wireless station being located near New York, the volume of the transmission received at New York will not be very strong, and while it may be possible

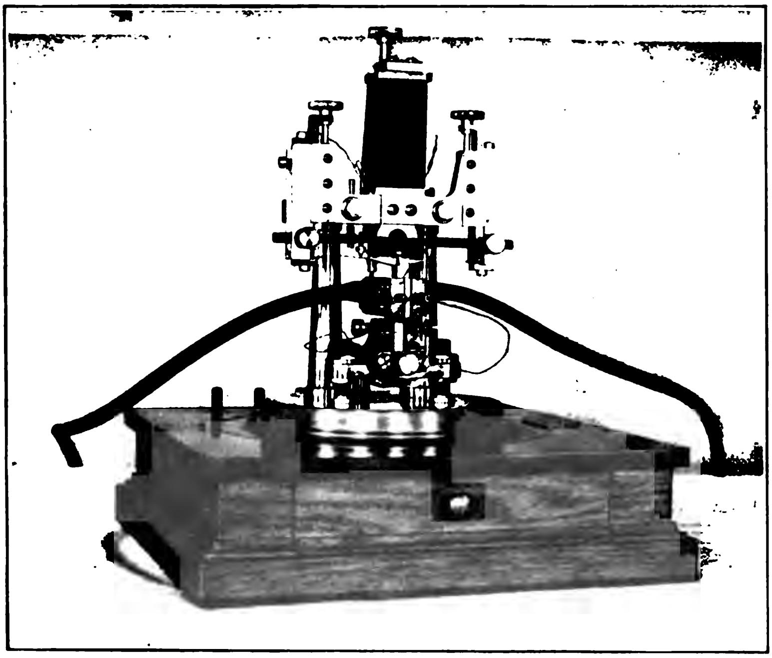


Fig. 26

to transmit it without amplification, amplification is advisable.

This receiver is a combination of the differential magnetic relay and the trough transmitter. An amplification of fifteen times can be obtained without loss of distinctness. The side electrodes of the trough are water-jacketed. The successful amplification depends upon the use of strong forces and upon keeping the moment of inertia of the moving parts as small as possible. Amplification may also be obtained by mechanical means but as a rule this method introduces scratching noises which are very objectionable even though comparatively faint.

Other types of transmitters have also been used, such as liquid jet transmitters, Fig. 27 transmitters operating by closing the air-gap in a magnetic circuit, and so changing the inductance of the oscillating circuit, etc.

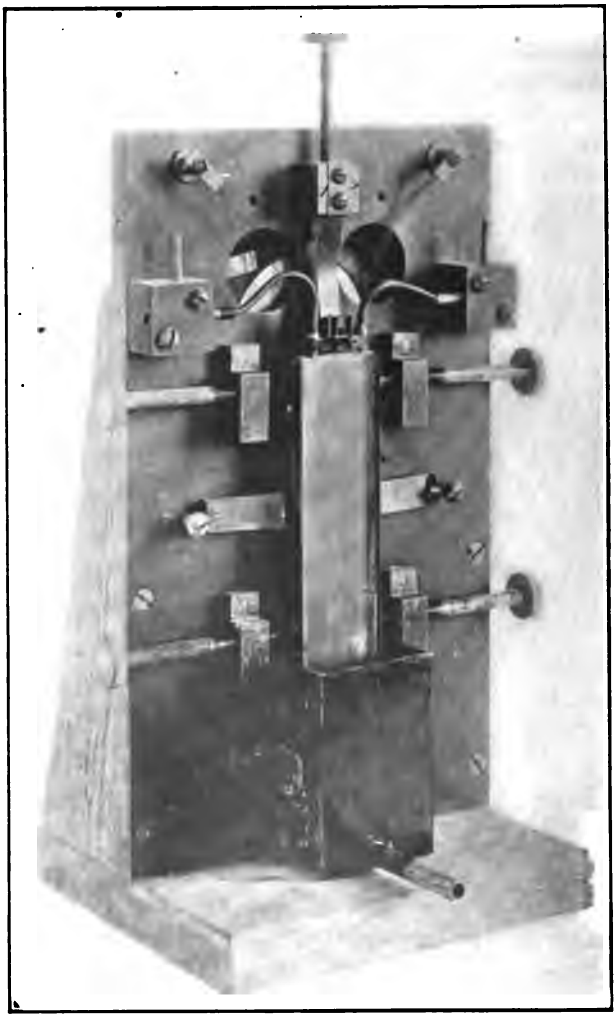


Fig. 27.

Fig. 28 shows a loud-speaking telephone receiver. A small iron disk is placed opposite a nozzle through which air at high pressure is blown. As is well known, this causes the disk to be held close to the nozzle. The telephone magnets alter the position of the disk and thus produce very loud talking.

The transmitting relays are connected in the wire line circuit in the same way as the regular telephone relay, except that in place of being inserted in the middle of the line they are placed in the wireless station and an artificial line is used for balancing. There is no difficulty met with on the wireless side of the apparatus, but on the wire line side there are the well-known difficulties

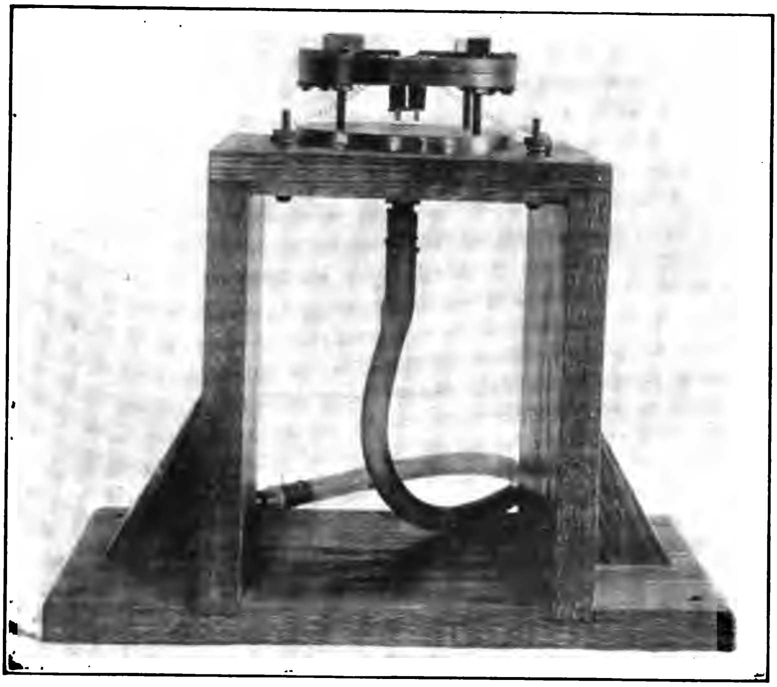


FIG. 28.

due to unbalancing which have not yet been entirely overcome. For the correction of these difficulties, therefore, we must look to the engineers of the wire telephone companies. At present the difficulties are if anything less than those met with in relaying on wire lines alone.

3. *Transmitting circuits.* Fig. 29[1] shows a type of arc circuit. Fig. 30[2] shows a suitable type of connection for use with a high frequency alternator.

1. U. S. patents Nos. 706,742, June 6, 1902 and 730,753, April 9, 1903.
2. U. S. patent No. 706,742, June 6, 1902.

Fig. 31[1] shows a type of circuit for use with the condenser transmitter.

Fig. 32[2] shows a type of circuit in which the modulation is accomplished by changing the inductance of one of the oscillating circuits.

As a matter of fact the transmitter may be placed almost anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity, the results obtained in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy and the circuit should be

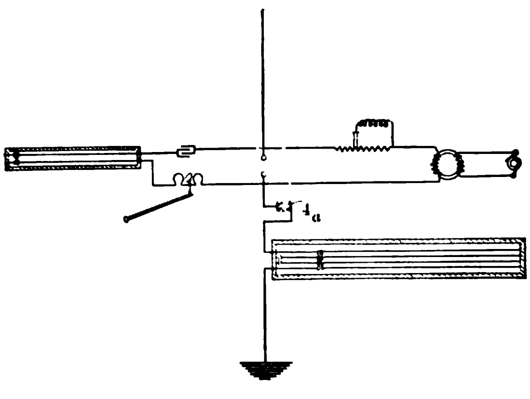


Fig. 29.

Fig. 30.

properly adjusted. Some success has also been attained by placing the transmitter in the field of the dynamo[3] but this method requires very careful designing of the field circuit.

4. *Receivers.* The receiver which the writer has found most satisfactory for general purposes is the liquid barretter. Fig. 33 and 34 shows this receiver. It consists of a fine platinum wire, about a ten thousandth of an inch in diameter immersed in nitric acid. Tests made with this receiver show that it responds without apparent loss of efficiency to notes as high as 5000 per second. Some very careful measurements recently made by my assistants, Messrs. Glaubitz and Stein, give the following results:

1. U. S. patent No. 706,747, Sept. 28, 1901.
2. U. S. patent No. 706,747, Sept. 28, 1901.
3. U. S. patent No. 793,649, March 30, 1905.

Voltage of high frequency circuit necessary to produce readable signals,	15×10^{-5} volts.
Ohmic resistance of receiver,	2,500 ohms.
Value of high frequency current necessary to produce readable signals,	6×10^{-5} amperes.
Electromagnetic wave energy required to produce audible note for period of one second,	1×10^{-4} ergs.

The telephone used for detecting the signals had a resistance of approximately 1000 ohms. Some measurements were made

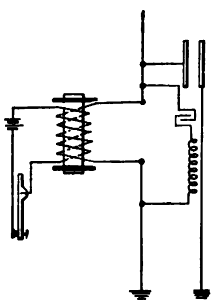


Fig. 31.

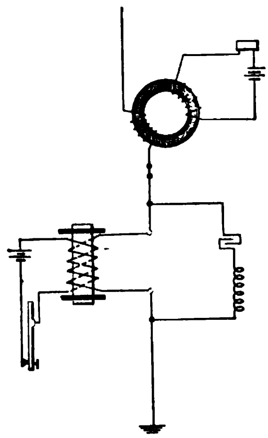


Fig. 32.

to determine the change of current in the telephone circuit by using a sensitive galvanometer in series with the telephone but the results obtained were obviously too low, possibly on account of the electrostatic capacity of the turns of the galvanometer with respect to each other. It will be noted that the amount of electromagnetic wave energy necessary to produce a signal is considerably less than that given in a previous note.[1] The difference is possibly to be attributed to improvements in adjustment and operation.

The above measurements were taken by shunting the barretter across a piece of straight resistance wire in series with a hot-wire ammeter, to determine the voltage necessary, and by intro-

1. *Electrical World and Engineer*, Oct. 31, 1905.

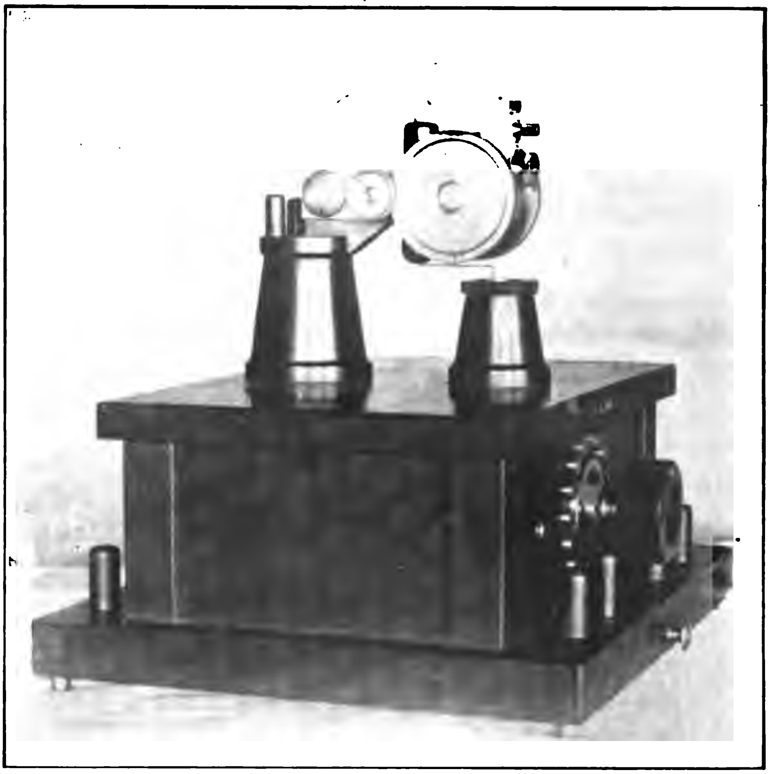


Fig. 33.

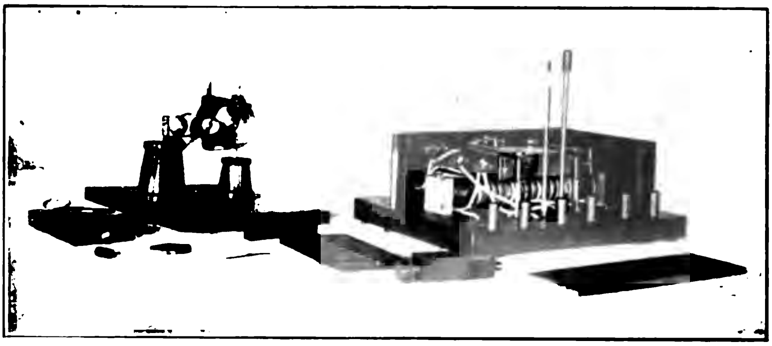


Fig. 34.

ducing resistance in series with the barretter to determine the resistance of the barretter. The figures were also checked in a number of other ways and very concordant results were obtained, so that it is believed they may be relied upon.

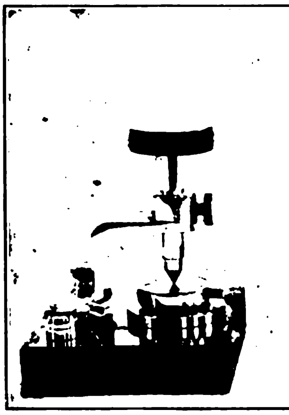


FIG. 36.

FIG. 35.

The previously mentioned thermoelectric receivers or rectifiers of Dr. Austin and Mr. Pickard shown in Figs. 35 and 36 and the vacuum tube receivers of Fleming, deForest, and Cooper Hewitt also act very satisfactorily. The fact that the writer

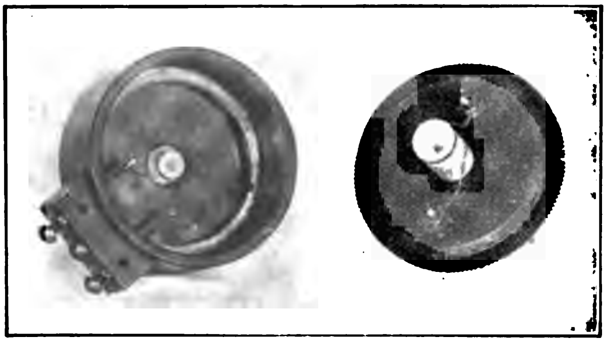


FIG. 37.

has not been able to get as good results from them may be due to greater familiarity with the liquid barretter and heterodyne receiver.

Figs. 37, 38, and 39 show forms of heterodyne receiver adapted for use for telephonic work.

5. *Receiver connections*. Where the wireless telephone is operated by first talking into the transmitter and then throwing a switch and listening, the usual wireless telegraphic connections

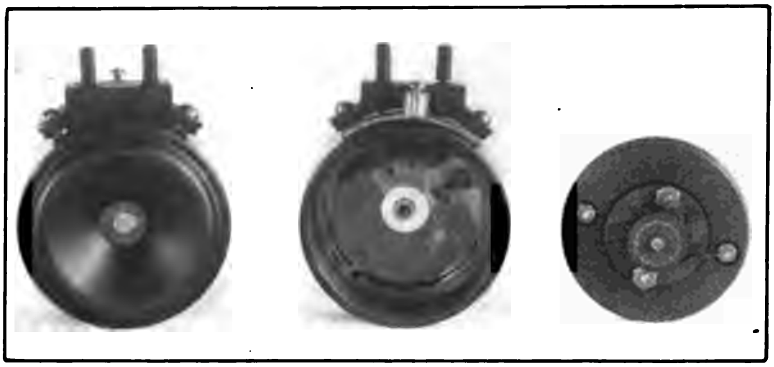


Fig. 38.

are used. This has been found in practice to be very inconvenient, however, and several methods have therefore been devised for talking and listening simultaneously, which methods

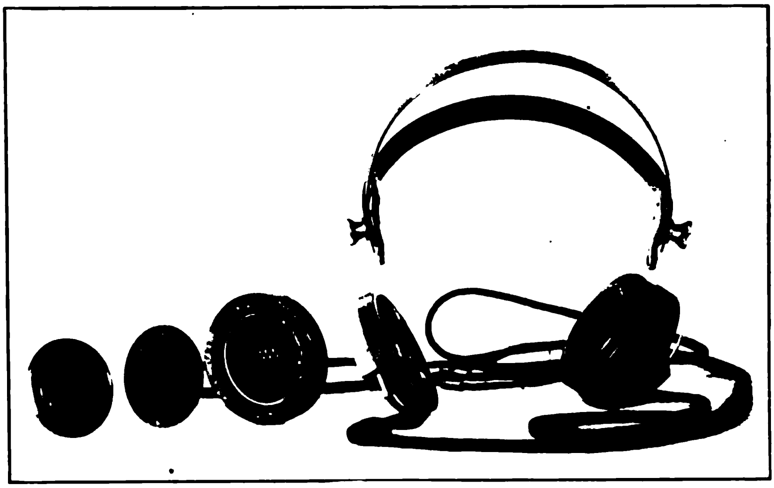


Fig. 39.

can, of course, also be applied to duplex wireless telegraphy. Among these methods may be mentioned the commutator method[1] and the balance method.[2]

1. U. S. application, 350,199, Dec. 31, 1906.
2. U. S. application, 366,528, April 5, 1907.

The former method is fairly well known and consists in rapidly connecting alternately the transmitter and receiver. The balance method consists in using a phantom aerial as shown in Fig. 40, where *P* is a phantom aerial, the circuit having such capacity inductance and resistance as to balance the radiating antenna. The apparatus is shown in Fig. 41.

In order entirely to cut out disturbances in the receiver while sending, an interference preventer, *I. P.*, the elements of which are shown in Figs. 42 and 43, is used in the receiving circuit.

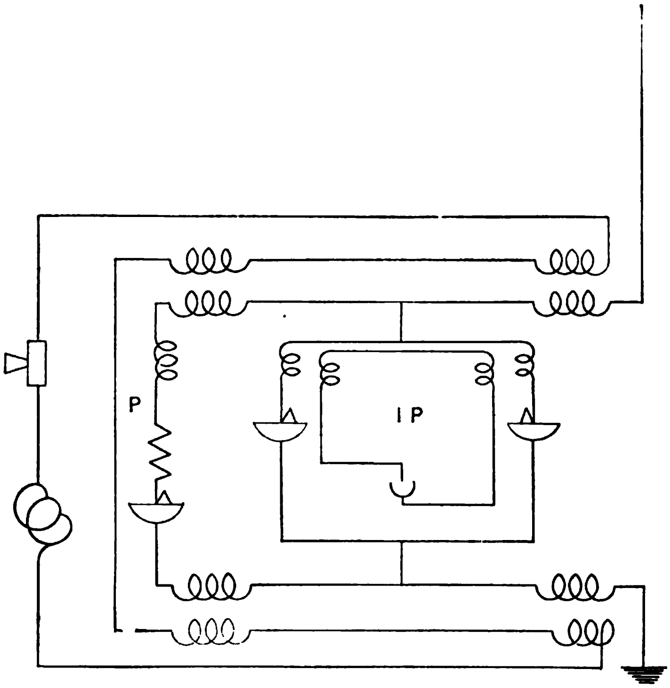


Fig. 40.

It may be here mentioned that balance methods work much better with wireless telephony and telegraphy than with line telephony and telegraphy, for the reason that the radiation resistance of an antenna is absolutely definite and is not affected by the weather, as are line circuits. Consequently, the balance can be made very sharp and once made does not need to be altered.[1] Of course, half the energy is lost but this is a matter

1. This method may, of course, be used for duplex working in wireless telegraphy. As some question has been raised in regard to the capacity of wireless telegraph lines the writer would say that he has received

of practically no importance, as the cutting down of the strength of a telephonic conversation to one-half is as a rule hardly noticeable, especially where there are no line noises or distortion of the speech through capacity effects.

6. *Receiving station relay.* The receiving station relay is similar to the transmitting relay shown in Fig. 26. The same

FIG. 41.

remarks apply to its use in connection with wire lines as to the transmitting relay.

messages at the rate of 250 words per minute by wireless and is now experimenting with apparatus designed to give 500 words per minute. With duplexing this gives 1,000 words per minute or 60,000 words per hour. The manager of one of the largest cable companies has stated (*London Daily Mail*, Sept. 24, 1907) that all the Trans-Atlantic cables together send 24,000 words per hour. It would appear, therefore, that if capacity alone be considered a single station on each side of the Atlantic can handle more traffic than all the present cables. It should be pointed out, however, that the mere ability to handle the messages is not sufficient and that unless the wireless telegraph companies obtain land facilities equal to those at present enjoyed by the cable companies they cannot handle the traffic as efficiency, *i.e.*, cannot deliver a message from New York to an individual in London and receive a reply in the same time. Fig. 44 shows a Wheatstone transmitter used for the test referred to.

F. Operation

As will be realized from the above, the operation of a wireless telephone system is very simple. The operator merely throws his switch to the position for telephoning and talks into an

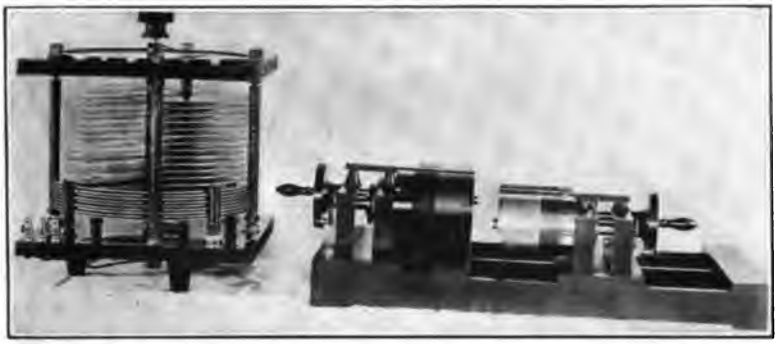


Fig. 42.

ordinary transmitter and listens in an ordinary telephone receiver. When the duplex method is used, as is always advisable, the conversation proceeds exactly as over an ordinary telephone line. Fig. 45 shows a phonograph transmitting music and speech wirelessly. Fig. 46 shows talking by relays from a local circuit.

Fig. 43.

I believe I am correct in saying that the transmission by wireless telephone is considerably more distinct than by wire line and that the fine inflections of the voice are brought out much better. This, I presume, is due to the fact that there is no electrostatic capacity to distort the speech, as in the case of wire lines, though I think the effect is also partly due to the absence of telephone induction coils with iron cores. Possibly some of the gentlemen present have witnessed the operation of the wireless telephone transmission between Brant Rock and Plymouth and between Brant Rock and Brooklyn. If so I think they will bear me out in saying that the transmission was clearer than over wire lines.

As a rule, there is absolute silence in the wireless telephone receiver except when talking is going on, though of course the usual noises may be heard if persons are walking across the room, etc. This makes listening in less of a strain than when talking over wire line. Even during severe atmospheric disturbances the talking is not interfered with to any noticeable extent, provided of course that an interference preventer is used.

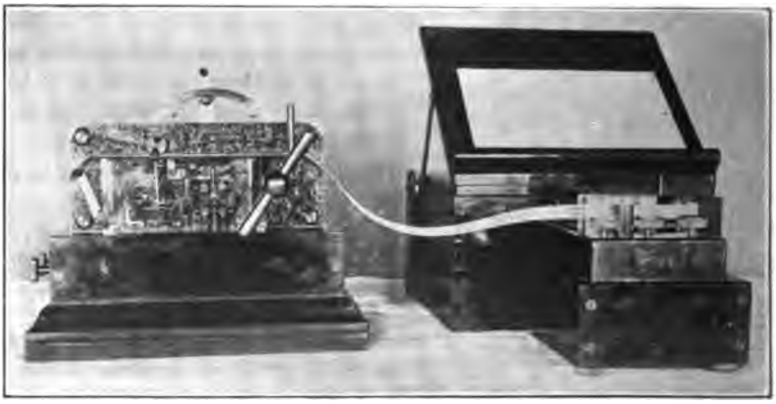


FIG. 44.

A comparative test was made with talking between Brant Rock and Brooklyn by wireless and by wire telephony. The talking over the wire line was done from a long distance station in Brooklyn. The wireless transmission was considerably the better. The fact that the wire line included in its circuits a cable from New York to Brooklyn was of course a disadvantage, but even allowing for this, practice and theory appear to be in agreement to the effect that transmission by wireless telephony over long distances is better than by wire line.

This method should be of especial value to independent telephone companies, which have their local exchanges, but no long distance lines, especially since no franchises or rights of way are necessary.

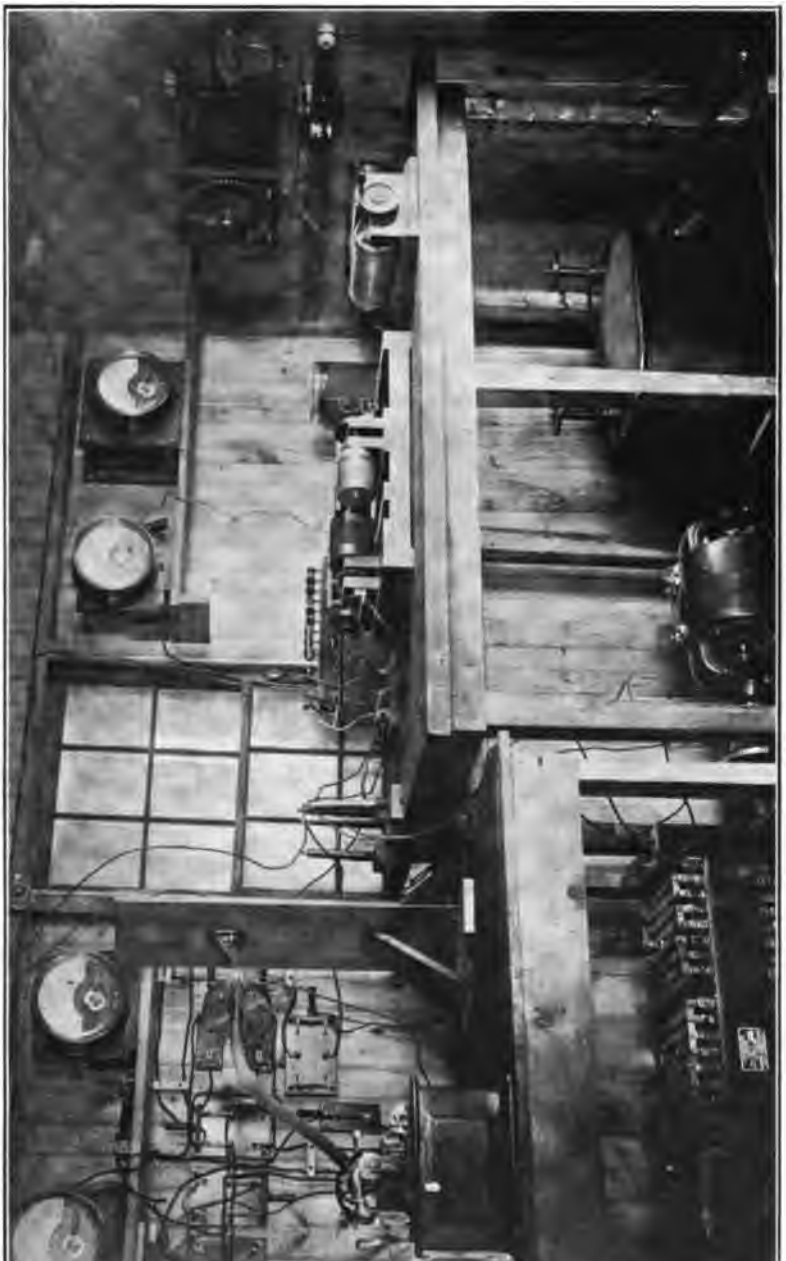


Fig. 45.

G. Possibilities

A. *Local exchanges.* There is no immediate prospect that wireless telephony will take the place of local exchanges. The difficulty in regard to the number of tunes can be overcome, but the fact remains that high frequency oscillations cannot be transmitted over wire and hence each subscriber must have his own generating station. At the present time no method is known which would be practical if placed in the hands of a subscriber. If such means should be found it would be very convenient to call up directly instead of through an exchange, but as I see it there are no immediate prospects of this.

B. *Long-distance lines.* I believe, however, that there is a

Fig. 46.

field for wireless telephony for long distance lines. The present long distance lines are very expensive to construct and to maintain, and a storm extending over any considerable section of country inflicts considerable loss on the telephone companies. Moreover, the distance of transmission is limited by the electrostatic capacity of the line, as I understand it. Wireless telephony would have the following advantages.

1. The initial cost would be very much less than that of wire lines.

2. The maintenance would be practically negligible in comparison.

3. In case of any breakdown, it would be right in the station and not at some unknown point outside on the line.

4. The depreciation would be comparatively small.

5. The number of employees required would be smaller.

6. The transmission is better, and as there is no distortion of the speech, the working distance is, it is believed, considerably greater.

7. The flexibility is greater. With wire lines a telephone company may not be able to give a Boston subscriber a line to New York, while having lines from Boston to Chicago and from Chicago to New York free. Operating wirelessly the wireless circuit normally used for operating between New York and Chicago and between Boston and Chicago could be used to operate from Boston to New York.

8. No right of way need be purchased and franchises it is believed, are not necessary.

It will be noted that I have not mentioned any disadvantages of wireless telephony for long distance work. I presume this is because I am not a telephone engineer. I hope the defects will be discussed by the experts who are familiar with telephone operation and therefore better able to point them out. Before leaving this part of the subject I would say that I think the question of interference has been worked out to such an extent that no serious difficulty need be feared in that direction.

C. *Transmarine Transmission.* Wireless telephony is peculiarly suited for this class of work. Pupin's ingenious and beautiful method has been successful at Lake Constance, Switzerland, I believe, but even assuming that deep-sea cables of this type could be laid and operated successfully, they would nevertheless be very much more expensive than wireless telephone stations. It is believed that wireless telephony will come into extended use for this purpose. Even without further development telephonic communication could be established between Norway or Denmark or Germany or Spain and Great Britain; between Sardinia and Corsica and France and Italy; between France and Algeria, between Australia and Tasmania and New Zealand; between the United States and Cuba and Porto Rico, etc, were it not that it is at present forbidden by law.

As regards telephonic communication between England and America, my measurements show that this should be possible with an expenditure of approximately ten kilowatts and suitably large towers say 600 feet high, or with some of the new forms of antenna. Whether such a transmission would be commercially valuable or not is another matter. Personally I do not see that it would, but when I remember that at the time when the telephone was first being introduced a number of eminent business men decided that the house-to-house printing telegraph would be more of a success commercially than the telephone for the reason that no one would want to do business unless he were able to have a record of the transaction, I must admit that there is a possibility of my being mistaken in this.

D. *Wireless telephony from ship to ship.* Here, of course, wireless telephony occupies a unique position. Wireless telegraphy has the disadvantage that a telegraph operator must be carried. The additional expense is an objection in many cases. The proposition that the captain or mate should also be a telegraph operator has not met with favor. Anybody, however, can operate the wireless telephone and almost every vessel carries an engineer capable of repairing the electrical apparatus in case of accident. The final arrangement will, I believe, (if we can prevent the governments from carrying out their proposed laws, forbidding wireless telephony), be this; that passenger vessels will carry a telegraph operator and use the telephoning apparatus for ordinary work and for telegraphing where it is desired to communicate over long distances. Other vessels will use the telephone alone.

E. *Wireless telephone from ship to local exchange.* This also will, I think, have considerable value, as enabling the captain of a vessel to communicate, by relaying over the wire line, with the owner of the ship, or enabling a passenger on a vessel to communicate with friends on shore.

F. *Range of wireless telephony.* 1. *Atmospheric absorption.* The great obstacle to long distance wireless telegraphy and telephony is atmospheric absorption. For short distances up to 100 miles in the Temperate Zone there is little difference between the strength of the signals at one time of the day and another. As soon as the distance is increased much over 100 miles for the Temperate Zones and 40 or 50 miles for the Tropics the signals at night are very irregular and there is great absorption during the day time. The daylight absorption may be so great that less than a tenth of one per cent. of the energy transmitted gets through. Some nights will be as bad as day-time while on other nights there will be apparently no absorption.

Fig. 47 is a curve showing the strength of the messages transmitted between Brant Rock, Mass., and Machrihanish, Scotland, at night, during January, 1906. Nothing at all was received that month during daytime.

The change in the strength of the signals is very sudden. In working from Brant Rock to Porto Rico, a distance of 1700 miles, the strength of the signals with short wave lengths would fall off to one one-thousandth of their former value during a period of less than fifteen minutes, while the sun was rising.

Early experiments showed that the absorption was greater as the wave length was increased and the effect was at first attributed to absorption in the neighborhood of the sending

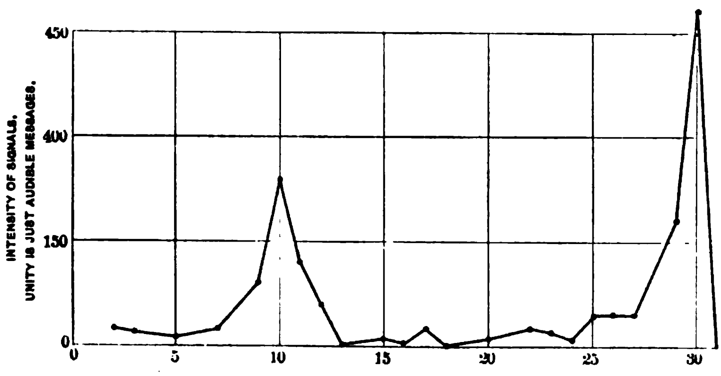


Fig. 47.—Curve showing variation of intensity of transatlantic messages for the month of January, 1906

station, and was thought to increase continuously with the wave length.[1] This fluctuating absorption at one time appeared to place a fundamental obstacle to commercial wireless telegraphy, as telegraph engineers will easily appreciate the impossibility of operating telegraph systems with circuits where the strength of the received signals may fall to one thousandth of its value

1. A mathematical explanation of this supposed fact was given by Dr. Fleming " Principles of Electric Waves Telegraphy " pages 617-618, 1906, the following conclusions being reached:

" Accordingly, the chief part of the weakening of the wave by sunlight is done in the neighborhood of the sending antenna, where the magnetic force H is greatest, and it is more sensible for long and powerful waves than for short and feeble ones. This agrees with the observations of Mr. Marconi ".

or rise to a thousand times its value in the course of a few minutes.

It was therefore considered absolutely essential, in order to decide whether long distance wireless telegraphy was commercially possible or not, to investigate this phenomenon fully. As a preliminary the station at Brant Rock sent to four or five other stations at varying distances and comparative readings were taken. The following table shows the general character of the results obtained:

Station	Distance	Strength of signals received on worst nights (strength of unabsorbed signals being taken as 1000).
Company's cottage	200 yards	1000
Lynn	30 miles	1000
Schenectady	170 miles	500
Philadelphia	270 miles	300
Washington	400 miles	150
Machrihanish	3000 miles	1

These experiments proved conclusively that the absorption did not take place in the neighborhood of the sending station, because the strength of the signals received at nearby stations was the same during the day as during the night while there was great variation in the strength of signals received at stations further away.

It was also found that the absorption at a given instant was a function of the direction as well as of the distance, since on a given night the signals received by stations in one direction would be greatly weakened, while there would be less weakening of the signals received by stations lying in another direction, while a few hours or a few minutes later the reverse would be the case.

This was thought to be connected with the coming weather conditions but before this fact is proved a much larger amount of data must be collected. Through the kindness of the U. S. Weather Bureau I was enabled to obtain a chart of the magnetic variations and on comparison of these with the absorption between the Massachusetts and Scotland stations there appeared to be a quite definite relation, *i.e.*, the greater the absorption the greater the magnetic variation. Here also, however, much more data is needed before arriving at a definite conclusion. The fact that the absorption did not take place in the neighborhood of the sending station having thus been definitely settled the next point to be investigated was whether or not there was any way of overcoming it.

The fact that variations in the absorption occurred with extreme rapidity, the absorption increasing sometimes a hundred fold in a single minute, and at night, when the effect could not be due to the sun directly, seemed to indicate that the body producing the absorption, whatever it was, was not in a state of continuity but was broken up into masses like clouds.[1] This also was in accordance with some experiments made in Brazil in 1905.

From optical theories it is known that where the absorption is produced by conducting masses of a more or less definite size the absorption is to a certain extent selective. The next point in the investigation was, therefore, to determine whether there

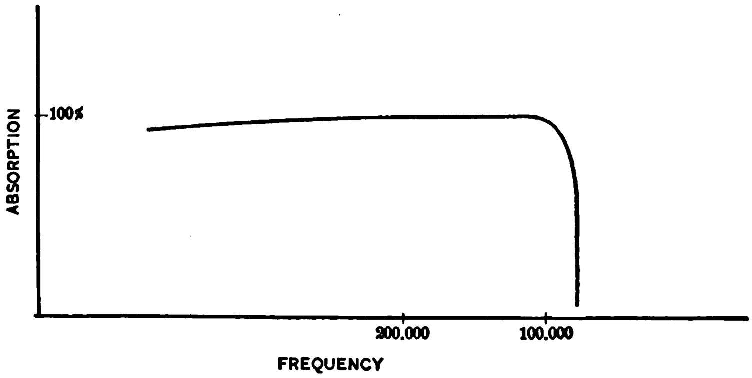


Fig. 47

was any possibility of this being the fact in the case of the absorption of wireless signals.

Comparative tests were therefore made of the absorption at night and during the day between Brant Rock and Washington, with wave lengths varying from a fraction of a mile up to four or five miles. It was found that the absorption did not increase continuously with the wave length but reached a maximum and then fell off with great suddenness.

Fig. 47 shows the general character of the curve, the ordinates referring to the amount of the absorption and the abscissas to the wave frequency.

1. *Electrical Review*, May 18, 1906.

It may be noted that the absorption is a maximum at a frequency of about 200,000 per second, nine hundred and ninety nine thousandths (0.999) of the energy being absorbed at this frequency during daylight, while for a frequency of 50,000 the absorption does not appear to be appreciable. Longer experiments, of course, might show some absorption, but in any case it is of a different order from the absorption for the shorter wave lengths.

Experiments were then made between Brant Rock and the West Indies, a distance of 1700 miles, during the spring and summer of 1907. It was found that the results were of the same character, *i.e.* that while there was greater absorption for frequencies of 200,000 there was comparatively little absorption for frequencies in the neighborhood of 80,000 and messages were successfully transmitted in daylight with this latter frequency. No messages were received in daylight with the higher frequency, though messages transmitted from the same station and with the same power and frequency were officially reported as having been received at Alexandria, Egypt, a distance of approximately 4000 miles.

The fact that these experiments were made during summer weather, and the receiving station was in the Tropics, and the fact that the distance, 1700 miles, was practically the same as that between Ireland and Newfoundland definitely settled the question as to whether long distance wireless telegraphy was a commercial possibility or not and the results were therefore published.[1]

Since the publication of the above results transmission has been accomplished by means of these long waves over still greater distances during daylight. Sig. Marconi early in October, 1907, abandoned the short-wave lengths previously used, and adopted one over two units in length, and immediately succeeded in operating between Glace Bay, Nova Scotia, and Clifden, Ireland a distance of more than 2000 miles, the frequency being approximately 70,000. The same messages were received at Brant Rock, Mass., a distance of nearly 3000 miles.

Still more recently Captain Hogg of the "Glacier" has written that during the southward passage of the Pacific fleet he received messages from the station at Brant Rock, Mass., while off Cape Ste. Roque, Brazil, S. A. The frequency used for sending was approximately 80,000, and the messages were

1. *The Electrician* (London), July 26, 1907.

received with the very interesting and sensitive silicon receiver invented by Mr. Pickard. This distance of 3000 miles is the greatest yet achieved by wireless transmission during daylight and would indicate that with the use of suitably high towers much longer distances can be reached.

2. *Range of wireless telephony and wireless telegraphy compared.* For the same power it is possible to telegraph to a further distance than to telephone. Distinct speech depends upon the presence of harmonics of a frequency as high as 1200 per second. The amplitude of these harmonics is according to some rough experiments made by the writer only about one per cent. of the fundamental frequency. Consequently, with a perfectly modulated transmitter 100 times as much energy would be necessary to telephone a given distance as to telegraph. It fortunately happens, however, that a carbon transmitter and also the circuits in which it is used, can be so constructed as not to modulate perfectly but can be arranged so as to accent the higher harmonics.

With transmitters arranged for the purpose good transmission has been obtained with thirty times the energy required to produce audible telegraphic signals. By still further modification the power required has been reduced to approximately ten times that necessary for telegraphing, curiously enough without noticeably distorting the character of the speech. There is one fact, however, which prevents the ratio from being as large practically as the instruments show, *i.e.*, speech can be satisfactorily understood with a less increase of power above a minimum audibility than telegraphic signals.

The amount of power necessary for wireless telephony may therefore be taken as approximately five to fifteen times that necessary for wireless telegraphy; *i.e.*, under the same circumstances and for the same power the wireless telegraph will carry two to four times as far. The difference in range would be very much greater also but for the curious fact that there is much less falling off with sustained oscillations than with intermittent groups of waves, even though the frequencies are identical.

This fact has been repeatedly determined by sending between Brant Rock and Brooklyn on the same frequency, using in the one case spark produced trains of waves and in the other the high frequency dynamo. The difference in the falling off for the same frequency and energy is very great but further work is necessary before anything very definite can be said about it or the reasons finally determined.

H. How Wireless Telegraphy has been Throttled by Governmental Action

The question has been asked why, if wireless telegraphy can compete with wire lines and cables, it is not put into operation. This is not an unnatural question. Ninety nine individuals out of a hundred would probably consider that if an inventor had perfected a system of wireless telegraphy or telephony so that it would operate reliably over long distances and would handle messages at a fraction of the cost of the present cables and without interfering with other stations, he would immediately pick out from an atlas half a dozen suitable points for operation, such as from France to Algiers, Italy to Egypt, Great Britain to Germany, New Zealand to Australia, Australia to Hong Kong, or Canada to Great Britain, and immediately commence commercial work, being perhaps delayed a few weeks on account of some slight formalities in connection with obtaining permits. The statement that nothing of the sort could be done would be received with incredulity, especially if it were known that the business men who would benefit by the reduced tolls were strongly desirous of having them put into operation.

This is a very important matter, not because the crushing out of a new system of telegraphy is so very important in itself, but because the prospects are that other branches of the electrical profession may have to face the same situation in the near future and it is, therefore, advisable to show in some detail just what governmental ownership means in its relation to the progress of civilization. I will, therefore, explain fully, but as briefly as possible how commercial wireless telegraphy is hindered by governmental action.

Examination of a chart of the world immediately suggests a number of points as suitable for the installation of wireless communication. For example the following:

1. United States to Cuba.
2. " " " Porto Rico.
3. " " " Jamaica and other West Indian Islands.
4. " " " Bermuda.
5. " " " Newfoundland.
6. " " " Great Britain.
7. " " " France.
8. " " " Azores.

9.	Newfoundland	"	Great Britain.
10.	Great Britain	"	Ireland.
11.	" "	"	France.
12.	" "	"	Spain.
13.	" "	"	Germany.
14.	" "	"	Denmark.
15.	" "	"	Norway.
16.	France	"	Algiers.
17.	Italy	"	Egypt.
18.	New Zealand	"	Australia.
19.	Australia	"	Hong Kong.

The first fact to be noted is that these countries with the exception of Porto Rico are foreign countries and that in practically every one of these, Porto Rico is believed to be the only exception, there are stringent laws in force forbidding the erection of wireless stations without permits. The difficulty of obtaining these permits is shown by the fact that one wireless company within the writer's knowledge has been endeavoring for more than four years to obtain permits in the majority of the above mentioned foreign countries and has so far succeeded in obtaining only one permit and that for direct communication between the United States and Great Britain.

To take a specific illustration. In 1903 an American company was requested to install communication between Bermuda and the United States. The principal industry of Bermuda is the growing of produce of various kinds, which is exported almost entirely to the United States. The only present means of communicating is through Nova Scotia, and in winter especially, owing to the delays on the land lines, the service is often quite insufficient. Permission was asked of the Home Government by the Bermudian incorporators, but without success.

A petition was then signed by virtually every prominent business man in the islands and forwarded to the Home Government. The members of the New York Produce Exchange drew up a petition and forwarded it to the Secretary of State requesting him to use his influence in the matter. The Colonial Office stated in reply that it was favorable to the project but that the matter must be referred to other branches.

The Bermudian business men also sent several representatives to Great Britain to urge personally the granting of the permit. After a lapse of several years a definite reply was received to the effect that the permit would not be granted. The Bermudians then took up the matter through a Canadian company which sent several representatives to interview the authorities in Great Britain but without success. The Lord High Commissioner of Canada, Lord Strathcona, finally was kind enough to interest himself in the matter and personally presented the case before the British authorities.[1] It is hoped by the Canadian company and the Bermudians that the permit will finally be granted, but this specific illustration will explain the difficulty in obtaining permits for operation.

As illustrating a different obstacle the case of Newfoundland may be taken. This is the natural point for establishing communication with Great Britain and the experiments previously referred to as having been made between Massachusetts and the West Indies showed conclusively that there would be absolutely no difficulty in operating commercially and with ease over this distance. On the other hand to operate directly from America is a much more difficult proposition for the reason that, as examination of a great circle chart will show, the whole of Newfoundland and Nova Scotia lies between any point in the United States north of Hatteras, and Great Britain.

If operation in Newfoundland were not forbidden by law half a dozen wireless stations would be at once erected, and the companies would be only too glad to pay into the Newfoundland treasury the ten or twenty thousand dollars per annum to be collected if they were put on the same footing as the cable companies in order to save the cost of the longer transmission. The Newfoundland government a number of years ago granted a monopoly of wireless telegraphy to one company, which company has never erected a transatlantic station in that island. While this monopoly has been very injurious to Newfoundland, on account of the loss of revenue entailed, it has been still more so to the wireless companies and to the public at large, which otherwise would have had cheap transatlantic telegraphy several years ago.

Another very formidable obstacle is the fact that in practically all the foreign countries referred to (and in Porto Rico) land telegraphy is a government monopoly. Consequently, the

1. Since the above was written a communication has been received from the colonial secretary stating that no decision will be given in the matter until the Wireless Company submits a plan for coöperating with the present cable companies (letter of Aug. 6, 1908).

wireless companies are entirely at the mercy of the government, are barred from collecting their own messages and must pay whatever tolls are fixed by the various governments. This, of course, also operates to prevent rapid service, since instead of communicating directly from Paris to London the messages would have to be sent from Paris by wire line to the French wireless station thence to the English wireless station and thence again by wire to London.

In a number of countries, the cable lines are also owned by their governments which makes them naturally averse to losing the invested capital or to permiting private companies to compete. It would be evident therefore that no matter to what perfection the art of wireless telegraphy is brought, years will elapse and the exercise of a great deal of political influence will be necessary before the public gets the advantages of the cheaper rates.

Ship communication. Here again the development of wireless working has been stifled by legislation. Vessel owners were at first rather slow to take up the matter of equipping their ships but after the system had proved its worth in several cases and some of the owners had had to pay large sums for salvage in cases where a wireless installation would have avoided the loss, its value began to be realized. It was at this point that the governments again stepped in with premature and injurious legislation. As a specific illustration, a United States company had arranged with the owners of some two hundred vessels to construct a line of stations from Maine to Texas, to operate with stations installed on the ships. The announcement was made that the administration proposed to recommend to Congress that wireless telegraphy be made a government monopoly.

A representative of the wireless company requested permission to submit some evidence to the effect that such a government monopoly was not necessary and that the various stations could operate without interference. A reply was received from the Administration that " information in regard to the subject was not desired ", and the administration recommended that wireless communication with ships should be made a government monopoly.[1]

It was proposed to carry this out as follows:

1. To establish Navy wireless stations at points along the coast

1. Recommendations of the Inter-departmental Board on Wireless Telegraph, 1904 submitted and approved by the Administration.

where wireless stations were needed by the merchant marine.[1-2]

2. To forbid the operation of private stations at these points.[3]

3. The Navy stations are to handle all messages to and from ships free of charge.

4. Wireless companies to be permitted, after obtaining a license from the Department of Commerce and Labor, to erect stations at points where there was no merchant marine business.[4]

The official approval and transmission of these recommendations by the Administration, although they were opposed and never went into effect, terminated, of course, all negotiations with vessel owners, since the owners would naturally not agree to contract for the transmission of their messages with the immediate prospect in view that the Government would transmit them free of charge. At the present time the masts ordered for the proposed line of stations are rotting at various points along the seaboard and the apparatus purchased for installation is deteriorating in storage.

The development of ship communication had just begun to recover from this blow when an International Wireless Telegraph Conference was arranged for by the various governments. In America no opportunity was afforded the wireless companies

1. *Ibid.* " That the maintenance of a complete coastwise system of wireless telegraphy by the Navy Department is necessary for an efficient and economical management of the fleets of the United States in time of peace and their efficient maneuvering in time of war. "

2. *Ibid.* " As fast as the naval wireless telegraph stations are in operation the Navy Department shall receive and transmit through these stations free of charge all wireless messages to and from ships, providing such stations do not come in competition with commercial stations, until such time as Congress may enact the necessary legislation governing this subject ". That the statement in regard to competition is disingenuous will be seen from examining the following extra Note 4, since only one station, and that a Navy one would be permitted at points where there was merchant marine business.

3. *Ibid.* " In asking for legislation on this point the board invites attention to the fact that where wireless stations are needed for the merchant marine, as a rule, the navy will also require them. The board believes it to be in the interest not only of governmental but of public economy and efficiency to permit the naval stations to handle the public service, for in the present state of the art but one station is desirable for the public interest in such places. It is admitted that there may be special cases where private stations can serve a useful purpose and the board believes that the Department of Commerce and Labor should have the duty of issuing licenses in such cases under such regulations as will prevent interference with stations necessary to the national defence."

4. *Ibid.*

of presenting the case to the delegates to the Conference, and a very stringent set of regulations was adopted. The Administration transmitted these regulations to the Senate.[1] The ratification of the treaty embodying these regulations was opposed by the Marconi Co., and by the National Electric Signaling Co. The following facts were pointed out:

1. That the proposed regulations virtually amounted to confiscation of the property of the wireless companies; that the working at present was carried on at a loss; that no wireless company was at the present time paying dividends; that the proposed rates would not permit of any return on the capital invested; and that the regulations would so limit the amount of business which it would be possible to transact that it would not pay to keep up the stations.

2. That the inventors in the art of wireless telegraphy had expended large sums of money in developing their systems, and such confiscation was therefore unjust and was thought to be unconstitutional.

3. That the regulations were impracticable in the following respects:

a. By requiring ships to use two tunes only[2] all stations were placed, so tc speak, on two-party lines, thereby producing a maximum of interference and preventing any one station working while any other was operating.

b. Allowing only five minutes per message and assuming only ten ships each with ten messages to be in the neighborhood of a given seaport, more than eight hours would have to elapse before the last station had transmitted its message. This time is believed to be underestimated, as the regulations provide that each ship before sending its message must call the coastwise station, have a number assigned to it, inform the coast station of its distance, its true bearing in degress, its true course in degrees, its speed in nautical miles, the number of words it has to transmit; must be informed how long it will have to wait, whether the transmission is to be in alternate order or in series, interrupt the sending after each 20 words, send an interrogation mark, wait for repetition of the last word, etc.[3] Hence it would be rather difficult to maintain the average time mentioned. This excessive delay would cut down the traffic to such an extent as to render it impossible for the stations to pay expenses of

1. Senate Document, Sixtieth Congress, first session.
2. Regulations II and III.
3. Regulations 19 to 26.

maintainance, and any telegraphic engineer will appreciate the difficulty of carrying on commercial business under such regulations.[1]

c. Placing all vessels on two-party lines introduces all the difficulties of the party line method and loses the only advantage, as it might easily happen that a ship in distress using one frequency might be within range of a number of vessels using the other frequency, but outside of range of any vessel using its own frequency. The obvious and practical method is legally to establish a single tune to be used exclusively for calling and distress signals but not for any other purpose; the transmission of messages to be continued by switching over to other tunes once the call has been received and accepted. In this way a ship in distress can always be sure of calling any vessel within range, while the transmission of messages can be carried on without interference and without one ship having to wait until the other is finished.

4. Its restrictions are of such a character as to prevent the future development of wireless telegraphy. For example.

a. The regulation[2] that all stations must carry a licensed wireless telegraph operator capable of receiving at twenty words per minute would prevent the installation of wireless stations on board the majority of ships since only the larger vessels can afford the additional expense of the operator. Many vessels would install wireless telephones which do not require a skilled telegraph operator, if it were not for this regulation.

b. The rules forbidding[3] the transmission of telegrams calling for repetition of messages, or for acknowledgement of receipt, or for telegrams to be forwarded, or for telegrams to be delivered by express or by mail, or for the transmission of money-order telegrams or for the transmission of telegrams with answer prepaid, or for the transmission of urgent telegrams are especially restrictive. By forbidding the transmission of telegrams of all the above classes the commercial field of wireless telegraphy is limited to such an extent as to deprive wireless telegraphy of its chief value.

1. As a practical illustration of this, on August 12, 1908, the Assistant Secretary of the Navy, on board U.S.S. Dolphin, had to wait two hours before an important message could be transmitted, as the two stations with which he was in range were occupied in sending a long message and the Dolphin was unable to cut in. Had a number of stations working on different times been available, this could not have happened.

2. Section 6, paragraph III.

3. Section XXXIII.

5. It expressly forbids the use of a number of the most important developments in wireless telegraphy. For example.

a. Section 3 in effect forbids long distance transmission in daylight. This section states that ships must not use wave lengths exceeding 600 meters. It is now well known that daylight absorption is very great for these wave lengths and that much longer wave lengths must be used during daytime. This rule therefore virtually forbids wireless telegraphy during daylight except within a very limited radius, and in case of an explosion or fire on shipboard during daylight the vessel would be unable to summon assistance unless by some fortunate chance another vessel happened to be within the radius limited by the restriction to the short wave length. It also virtually prohibits ships keeping in communication with the shore for more than twelve hours out of twenty-four.

b. Section 3 states that the system employed must be a syntonized system, thus forbidding the use of systems such as the heterodyne system which do not depend for selectivity on syntony. This would not be so injurious if it were not for the fact that the present indications are that syntony will in the near future be abandoned as a means of obtaining selectivity.

c. The rules of Section 2, 3, and 18 to 26, virtually forbid the use of duplex and multiplex systems. There is no reason why a number of ships should not communicate with the same station simultaneously, but the above rules forbid this by requiring only two wave lengths to be used and the messages to be taken one after the other.

d. It is premature. The expression " that an art is in its infancy " is a very hackneyed one but if it can be applied properly to any art it is to wireless telegraphy. The fact that the proposed regulations are unsuitable does not reflect in any way on the ability or conscientiousness of the delegates, though it would seem that it would have been advisable to consult the engineers of the various wireless telegraph companies before drafting the rules. The main difficulty, however, is that no one, no matter what his knowledge of the present state of the art, can foresee the future developments. The question of wave length and daylight absorption is an illustration of this, as is also the question of syntonized circuits. The time has not yet come for any such hard and fixed regulations as thus proposed.

6. It was also pointed out that the public had no rights in

regard to wireless telegraphy, since a patent differs from a franchise in that when the public grants a franchise it gives a right in respect to something which already exists and which it owns, and it therefore has a right to make what stipulation it chooses. In the case of a patent, however, the right is not given in respect to something which the public owns, but in regard to a new creation which exists merely in the mind of the inventor, to be called into being or not at the inventor's will, and therefore a thing in which the public has no right except as it obtains one by stipulation with the inventor. In the case of wireless telegraphy the companies invested their money under the patent law contracts with the various governments, and therefore the inforcement of regulations of the character proposed without the consent of the inventors is a breach of contract.

As a result of the hearing and of representations supporting the position of the wireless companies made by a very eminent electrical engineer the Senate Committee has decided to do nothing for the present in the matter. During the hearing the fact was brought out by the committee that the proposed regulations were passed upon the assumption that interference could not be kept out, and that the U. S. Navy had already made official reports on tests of interference preventers which showed that this was not the fact. On direct question by the Senate Committee the representative of the U. S. Navy present at the hearing freely admitted that it was a fact that interference could be kept out.

Still more recently another set of recommendations has been forwarded by the Administration to the Senate endorsing the recommendation of the Secretary of the Navy that a law should be passed[1] making it an offence punishable by imprisonment for one year of a fine of $2,000 or both for a private station to continue sending when called upon to discontinue by a Navy operator, or to produce interference with a Navy station when the latter is transmitting an official message. This recommendation was not accompanied by any recommendation to the effect that the Navy stations should use any means for keeping out interference. Before the transmission of this recommendation a conference was sought with the Navy officials with a view to drafting a form of regulation which would accomplish the results sought, without placing the wireless companies at the mercy of

1. *Congressional Record*, Feb. 14, 1908. Also H. R. bill 17719, 60th Congress, 1st Session.

the Government and without virtually confiscating their property but it was found impossible to obtain a hearing.[1]

The following memorandum of a portion of the interview between Secretary Straus of the Department of Commerce and Labor and the representative of the wireless company, asking for a hearing, will be of interest:

REPRESENTATIVE: "Will you not, Mr. Secretary, be willing to assist us in obtaining a treaty which, while giving the government all it desires in the way of intercommunication between different systems, reservation of wave-lengths for government purposes, etc., will, at the same time, avoid driving the wireless companies into bankruptcy?"

SECRETARY STRAUS: "The treaty was reported by the experts of the government departments, and we propose to carry it out, as it is the policy of the administration."

REPRESENTATIVE: "But, Mr. Secretary, these regulations virtually prevent the wireless companies from doing any commercial business. With everybody on one party line, even without the numerous other restrictions, it will not be possible to handle a sufficient number of messages to pay operating expenses, and the companies will necessarily be forced out of business."

SECRETARY STRAUS: That has nothing to do with this department. If you are injured you should go to the Congress and ask them to reimburse you.

REPRESENTATIVE: Mr. Secretary, you know that it would be practically impossible to get a bill to reimburse a private company through the Congress. Why should the government crush out a new and important method of communicating which will save the country millions of dollars yearly, when the government will gain nothing by the action. We feel that your department ought to assist us in this matter.

SECRETARY STRAUS: It has been decided by the administration that the treaty should be approved as it stands.

It will be noted that this conversation took place in the United States, and not in Russia, as might possibly be otherwise inferred. It will appear from this and the experience of others that the original object of the formation of the different government departments has been rather lost sight of in recent years.

It will perhaps be seen that the difficulties in the development of wireless telegraphy have not been wholly of a technical nature and more patience may perhaps in the future be extended to those engaged in the work.

In his book entitled "Public Ownership and the Telephone in Great Britain," Professor H. R. Meyer has treated specifically of the way in which the use of the telephone was opposed in Great Britain, by the English postal authorities with the object

1. See also appendix.

of, to quote the Postmaster General, Sir James Ferguson, "Guarding the Post Office monopoly." Professor Meyer shows how out of 77 companies which applied for licenses from 1882 to 1884 only 8 companies succeeded in obtaining permission to work, and how the various authorities prohibited the telephone companies from laying cables in the streets or from opening long-distance pay stations or from building trunk lines in order to force the public to use the telegraph instead of the telephone. It would appear that the same line of policy in a still more aggravated form has been adopted in connection with wireless telegraphy.

Considerations

The subject is, however, one which is bound to concern in the near future other branches of the engineering profession than those now affected and the present appears to be a suitable time for considering the matter more broadly.

Whatever the ultimate object of man's existence may be it is tolerably certain that it is not to occupy his entire mental activity with the question of how many grubs he can secure for food and where he can find a suitable hollow tree in which to spend the night. But whatever we have above this is due solely to the inventor (in which term I include not only the men who discovered how to produce fire and to build houses and steam engines and alternating current motors, and therefore all engineers whether they take out patents or not, but also those who discover how to distribute what is created in such a way as to make it available).

In the state of nature which Tolstoy so greatly lauds and so carefully avoids advance is impossible; all available energy of mind and body is necessarily employed in the problem of maintaining a bare existence. Before we can advance toward our goal, whatever it is, we must first have time and opportunity and a means of maintaining any advance. That we have this time and opportunity is due to the fact that by means of innumerable inventions we are rendered every day less dependent upon the accidents of nature. It would therefore appear, that whatever our ultimate goal may be, the first essential for reaching it is an increased control over the forces of nature.

This increased control can only be obtained through intense effort. When we see a performer at a circus contorting his body into apparently impossible positions we realize the peculiar aptitude and the many years of training which must have been necessary. It is not generally realized, however, that a still more peculiar aptitude and many more years of still more intense training are necessary for those who would do useful work in any branch of mental achievement. We seldom think, in reading a mathematical paper for example, that the author has studied possibly for an average of ten or twelve hours a day for twenty or forty years before achieving sufficient proficiency in his subject to be able to accomplish the work.

To obtain results in a special line therefore a man with special aptitude and training is required. In addition to this there must be the opportunity. Hundreds of thousands, and in many cases millions of dollars are necessary for the development of an important invention. Such sums will not be furnished if there is no prospect of a return. As the success of an invention is always doubtful, the return from a successful invention must be sufficient to cover the losses from the much larger number of failures, for if the average return from one hundred inventions falls below that obtainable from mortgages or other forms of secure investment there will be no incentive.

The following question seem to me to be worthy of consideration:

1. Whether public officials, elected by the people, would consider themselves justified in expending millions of dollars on the development of inventions the success of which was uncertain.

2. Whether the best men to develop such inventions successfully would be found among the Government officials available.

3. Whether development can be expected in an art or industry entirely under Government control or ownership.

4. Whether universal Government control or ownership does not necessarily involve a fixed and non-progressive state as opposed to a state of progress and development.

Appendix

In the United States some additional hindrances on the part of the Government have been met with. For example, in the United States, and in Russia, as well, an inventor has no legal remedy in case the Government appropriates his invention.[1] It might be thought that the inventor could protect himself by suing infringing companies, but this is not so.

The wireless sets originally used by the United States Navy

1. Russel *vs.* United States, decided in 1900, 182 U. S. 516.

were imported from a country which was not at that time under the Patent Convention, and as they were purchased abroad no action could be taken. The then Secretary of the Navy, Mr. Moody, refused to require the foreign company to appoint a responsible representative in America. It was not until some years later, when, Mr. Morton being Secretary and the matter having been taken up by one of the Senators, this was done, and an injunction was obtained against the representative so appointed.

On further protest the next Secretary of the Navy, Mr. Bonaparte, stated that the patents could not be recognized as they had not been sustained. He was again approached but said that he had decided that he was not bound to respect them as he considered the price too high.[1] He declined, however, to allow the price to be fixed by arbitration, stating that he considered that the price should be fixed with reference to the cost of manufacture solely. It was pointed out that as the cost of labor and material of the particular device concerned amounted to less than a dollar and as a fair manufacturing profit on this would not be more than forty cents, this would afford no means whereby the company would be reimbursed for its expenditure of several hundred thousand dollars in developing the apparatus. To this Secretary Bonaparte replied that that was a matter which concerned the company and that his department had nothing to do with that. The principal infringing companies having been enjoined the Navy and Army began manufacturing the devices themselves in quantities.

Through the influence of one of the Senators the matter was again taken up and it was arranged that the Secretary of the Navy, Mr. Bonaparte, should obtain a legal opinion from the Attorney-General in regard to the matter. This opinion was prepared by one of the Attorney-General's assistants and proved to sustain the claims of the wireless company on every point. Before it was finally transmitted the Secretary of the Navy, Mr. Bonaparte, withdrew his request for an opinion.

The wireless company received a letter[2] from the Navy Department to the effect that by order of the Administration the patents had been turned over to the Navy Department. A written request[3] was forwarded to the Administration, pointing

1. Letter April 19, 1906.
2. Letter No. 137,244, July 11, 1906.
3. Letter April 3, 1907.

out that the above-mentioned property had been confiscated by the Government without a hearing and asking for a hearing. No reply was received.

The above is given as an illustration of the effect of the present law under which an inventor has no legal remedy against the confiscation of his patents by the United States Government. Among other recent instances of confiscation of inventions by the Government may be mentioned those of the Krupp and Armstrong Companies, the San Francisco Dry Dock, etc.

As the situation is not generally understood attention is here called to it. It should be remedied, as it operates very injuriously as regards the Government departments themselves. The Government is deprived of the services of American inventors who either place their talent at the disposal of other countries, as in the case of Hiram Maxim, or turn their attention to other lines. The general result is that the United States Government, instead of leading other nations, is obliged to follow after and copy, though the success of the United States Navy in developing submarine boats is an illustration of what can be accomplished in cases where the inventor has been able to develop his work without confiscation.

In 1906 President Roosevelt's attention was called to the above facts. He was asked if the administration would not introduce a bill to remedy this state of affairs. He replied that the administration had too many bills of its own to look after, but, on further inquiry, stated that if such a bill was introduced the administration would not oppose it.

On the strength of this promise a bill was introduced and unanimously reported, as follows:

House of Representatives, 60th Congress, 1st Session, Report No. 184

The Committee on Patents, to whom was referred the bill (H. R. 7653) to amend section 4919 of the Revised Statutes of the United States, to provide additional protection for owners of patents of the United States, and for other purposes, have considered the same, and recommend that the bill do pass with the following amendment:

In line 7, page 1, strike out the words " has been or," and insert the word " hereafter " after the word " shall."

A bill substantially the same as that now reported was passed by the Senate at the last Congress, and favorably reported to the House, but at too late a day in the session to receive consideration.

The object of the bill is to provide for owners of United States patents a remedy for the taking of their property by the United States for public use, when such taking occurs without the license or authority of such owners and without compensation.

In England and in practically all over civilized countries, except Russia and the United States, the Government can not appropriate an invention without paying a fair price for it. A regular tribunal is charged with the duty of determining what is a fair price for the use of an invention appropriated by the Government in case the Government considers the inventor's charge to be excessive. The United States habitually appropriates at its pleasure the patented inventions of its citizens and declines payment therefor. And this notwithstanding the fact that according to the decisions of the Supreme Court a patent of the United States is property within the meaning of the term as used in the Constitution and laws of the United States, and the use of a patented invention by the Government is a taking of private property, which can not be done lawfully without compensation to the owners. (Solomons *v.* United States, 137 U. S., 342, 346; McKeever *v.* United States, 14 Ct. Cls., R., 396; Affirmed S. C. 18 Ct. Cls., R., 745.)

But notwithstanding this right to protection which patentees and other property owners derive from Article V of the Amendments to the Constitution, it has been held by the Supreme Court that the owner of a patent can not restrain its infringement by the United States or an officer or agent of the Government. (Schillinger *v.* United States, 155 U. S., 163 (1894); Russell *v.* United States, 182 U. S., 516 (1900).)

In both of these cases the court held that in the absence of an express contract between the Government and the patentee, or transactions between them from which a contract may be implied, no court of the United States is vested with jurisdiction to entertain a suit or action by a patentee seeking to recover compensation for the use of his invention by the Government.

How next to impossible it would be to make a case of implied contract which would render the Government liable under the court's decision may be inferred from the following statement of the facts appearing in the Russell case just cited. It there appeared that at the Government's invitation Russell exhibited his patented invention to a board of officers appointed by the Secretary of War. The Government announced that it would adopt and use a device embodying his invention. Prior to the adoption and use of the device Russell communicated his patent to the War Department, showing that his patent covered the device and tended the use of his invention to the Government for reasonable compensation. The Government proceeded to use the device without denying Russell's right to compensation, but with the remark that he should seek his remedy by some means other than Executive action. And the Russell case is only a sample case; one of many.

It seems to be necessary and proper to provide for patentees a remedy, such as the passage of this bill will secure, for the invasion of their rights. Without such remedy, patentees are the only persons who are outside the protection of Article V of the Amendments of the Constitution. "Nor shall private property be taken for public use without just compensation."

Without such remedy a patent is not what it purports to be on its face. Many inventors have spent years of their lives and practically bankrupted themselves in developing inventions primarily of use to the Government, only to find in the end, after their property has been seized by the Government, that they have no legal means of redress, and that the governmental Departments will not recognize the decisions of the courts.

Without such remedy there is a ridiculous discrimination between inventors. The inventor of a children's game or of a new brand of chewing gum is protected by the courts. But the inventor of a device which may save the nation from an humiliating defeat in time of war, or reduce the cost of carrying the mails, or reduce the number of shipwrecks on the coast, is afforded no protection; the governmental Departments have the power to confiscate his property and habitually exercise that power. It may be a new type of breech mechanism, or a dry dock, or a method of communicating with ships at sea; if the invention is valuable the Government can and does seize it, though the inventor may have spent years of his life and bankrupted himself and his friends in developing it.

It may be conceded that the Government ought to have the right to appropriate any invention necessary or convenient for natural defense or for beneficent public use, and that, too, without previous arrangement or negotiation with the owner. Nevertheless, the appropriation having been made it would seem that justice to the citizen demands that in due time he should receive fair compensation for his property.

The claim is made by some that the Government, being the grantor of the patent, ought to have the right to use without compensation such inventions as are necessary for its purposes.

One answer to this is that there is no such limitation or reservation in the law governing the granting of patents; and another answer is that if that were the law there would be no time, brains, or money spent by anyone in inventing those things for which there would be no remuneration.

But it is useless to multiply reasons to justify the passage of the bill. The one fundamental reason already assigned is unanswerable—that no American citizen's property can be appropriated for public use by the Government or by anyone else without compensation being made therefor.

The amendment proposed, by striking out the words " has been or " and the use of the word " hereafter," in line 7, page 1, is deemed advisable, that there may be no question arising upon statutory construction that the law is not retroactive in its effect, but will apply only to future appropriations of patents by the Government.

It passed the House of Representatives by a large majority, the leaders of both the Republican and Democratic parties speaking in favor of it. It passed in the Senate unanimously. It did not become a law, however, as President Roosevelt declined to sign it, though its signature was strongly recommended by Secretary Taft, Senator Knox, and others. No reason was given by President Roosevelt for declining to sign the bill, but it is understood that his action was due to the fact that the ratification of the proposed wireless treaty had been opposed by one of those interested in the passage of this bill.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N.J., June 29, 1908.

THE MEASUREMENT OF ROTARY SPEEDS OF DYNAMO MACHINES BY THE STROBOSCOPIC FORK

BY A. E. KENNELLY AND S. E. WHITING

It is the object of this paper to call attention to what has already been accomplished by others in the direction of measuring rotary speeds with the stroboscopic fork, and also to a certain new modification of the principle which has been developed by the authors.

Definition. A stroboscopic fork consists essentially of a tuning fork, such as is shown in Fig. 1, carrying at its extremities a pair of thin strips, or flat shutters, in the plane of vibration. A narrow slit is cut in each shutter parallel to the fork's length. These slits lie opposite to each other when the fork is at rest, so as to permit an observer to see through both slits in this condition. When the fork is thrown into free vibration, the line of vision is interrupted by the vibrating shutters, except during a very brief interval once in each alternation, or twice in each complete cycle, of the fork's vibration, when the slits pass each other, moving rapidly in opposite directions. If then the fork makes say 60 alternations per second, corresponding to a vibration frequency of 30~, there will be 60 brief visual stimuli per second admitted to the retina of the observer's eye. If the object under inspection through the shutters is rotating in such a manner that consecutive retinal images are similar and symmetrical, the picture apprehended by the observer will be continuous and stationary; that is, the object will appear to stand still. Moreover, a certain cyclic range of departure from strict uniformity in the successive images formed on the retina will give an impression of a continuously rotating picture.

If the appearance presented by a rotating object is stationary, when viewed through a stroboscopic fork, we know that the speed of the object's rotation is constant, and also that it bears some simple numerical relation to the speed of vibration of the fork. Since the rate of a tuning fork's vibration is remarkably constant, is nearly independent of temperature changes, and can be determined once for all with great precision, the speed of rotation under inspection becomes known with a like degree of precision.

Brief historical outline. The stroboscopic fork has been known and used by physicists for some time. It has been used, for example, in the Lorenz method of determining the absolute value of the ohm.[1] In the Lorenz apparatus, a stroboscopic fork has been used to measure the speed of rotation of a small driving motor to within one one-hundredth of one per cent. Although stroboscopic methods have been used to some extent in engineering tests, the stroboscopic fork has only recently been employed for measuring the speeds of dynamo machinery. The stroboscopic fork was described in this connection in a paper

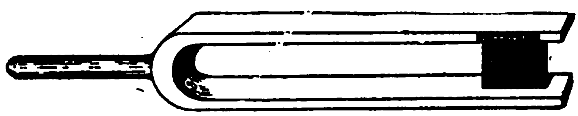


FIG. 1—Stroboscopic fork

on "Stroboscopy", by Dr. Charles V. Drysdale, read at the Optical Society London in 1905, and shortly afterwards reprinted.[2] Figs, 1, 2 and 3 are taken from that paper. The tuning fork he employed was like that in Fig. 1, held in the observer's hand and excited into vibration at suitable intervals, by mechanical impulses, such as a light blow on the knee. The vibration frequency of the fork was 50 cycles per second, or 6000 peeps per minute. The target shown in Fig. 2 was mounted concentrically on one end of the rotating shaft whose speed was required to be measured. At every 100 revolutions per minute of the shaft, (*i.e.* 100, 200, 300, etc., rev. per min.), the serrated edge pattern of this rotating target would appear stationary. Moreover, at certain speeds, the square, the pentagon, and the hexagon would severally appear stationary. Fig. 3 represents

1. "Absolute Measurements in Electricity and Magnetism", by A. Gray, London, 1893, Vol. II, page 594.

2. "The Optician and Photographic Trades Review", Dec. 8 and 15, 1905.

the retardation speed-time curve of an unloaded motor, after switching off, obtained by stroboscopic-fork observations.

A paper on "Accurate Speed, Frequency and Acceleration Measurements," by Dr. Drysdale, appeared in the "*Electrical Review*," of London, for September 7 and 14, 1906. Figs. 4, 5, and 6 are taken from that paper, which describes an electrically driven fork, as seen in Fig. 4, the details being given by Dr. Drysdale in Fig. 7. The standard vibration frequency is 50 cycles per second, and the target described was the same as in the previous paper, Fig. 2. Fig. 5 illustrates the device

FIG. 2—Stroboscopic target

for calibrating the fork. This fork, *F*, is mounted in front of a small shunt motor that can be accurately controlled in speed with the aid of the hand rheostat, *R*. The motor is driven in synchronous relation with the fork, as evidenced to the observer by the standstill of the pattern on the target, *T*. The revolution-counter, *C*, geared with the motor shaft, is then allowed to register for say ten minutes by a stop-watch; so that the record of the counter, *C*, during that time enables the uniform speed of the motor, and of the fork, to be determined closely.

For rotary speeds intermediate between those at which the target patterns appear to stand still, the simple stroboscopic fork of Figs. 1, 5 and 7 can only serve to measure speeds indirectly, by enabling the observer to count the apparent revolutions of the target image during say one minute by the watch. For example, if the motor's speed was say 1200 rev. per min., the target, viewed through the fork, would appear stationary; but if the speed increased to 1220 rev. per min., the target would appear to rotate 20 times per minute in the direction of motion. It is desirable for many purposes, however, to bring the picture of the target to a standstill at any or all steady speeds within the ordinary range. Dr. Drysdale effected this in the

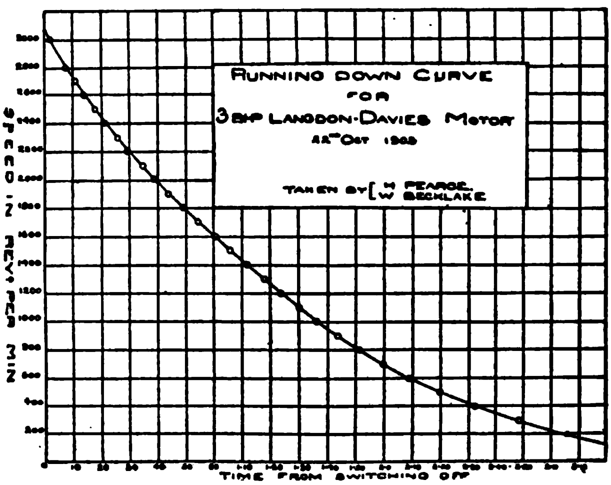


FIG. 3

manner indicated in Fig. 6. The conical roller, R, was driven by a sort of direct-current synchronous motor, M, which in its turn was operated by current impulses from the electrically driven standard fork. A thin disc, D, with radial slots, runs on the surface of the conical roller; so that by moving the disc from the smaller to the larger end of the cone, the speed of the disc's rotation could be increased and regulated very definitely. In this way the number of peeps per minute can be brought into synchronous relation with the number of revolutions per minute of a target on a rotating shaft under observation, and the coincidence is rendered manifest by the picture of the target pattern becoming stationary, when viewed through the rotating slots.

Dr. Drysdale's paper set forth the advantageous application of the stroboscopic fork to the measurements of acceleration, retardation, uniformity of speed, frequency and slip.

The stroboscopic fork has also been employed in the United States by Dr. Northrup for adjustably varying and controlling the speed of a small alternating-current generator or converter.

The convenience and precision of the method employed by Dr. Drysdale was observed by one of the writers of this paper on the occasion of a visit to the Northampton Institute, London, in 1907. The writers believe that his method only requires to be more generally known in order to be used extensively. A simple stroboscopic fork, such as is shown in Fig. 1, selected for the right frequency, is sometimes capable of being used as a speed measurer of an engine, or as a frequency measurer of an

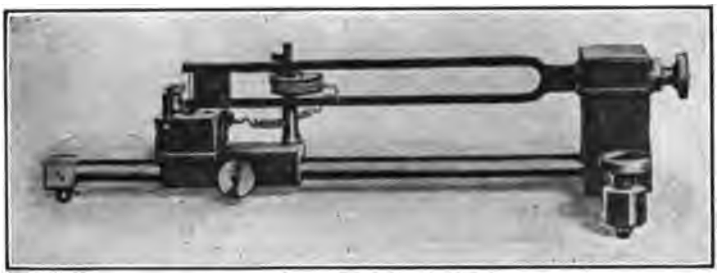


Fig. 4—Electrically driven tuning fork, with slits

alternator, without even the use of a special target, by watching the spokes of its flywheel, in a fairly good light, through the slits of the fork. Such a fork can maintain a satisfactory amplitude of vibration for more than half a minute at a time after being set in vibration, is very portable, simple, and not easily deranged, under ordinary care.

New modification of the stroboscopic fork. The great advantage of the stroboscopic fork is that when it is vibrating in synchronous relation with the rotating target, the latter appears stationary, and very small changes in speed may then be readily detected. For example, if the target on the rotating shaft makes 1200 rev. per min., and appears stationary through the fork slits, an increase or diminution of one rev. per min., or one-twelfth of one per cent. in the speed, would cause the picture to rotate once per minute forwards or backwards respectively, a rate of rotation that is readily capable of being noted by the observer. The difficulty is that, in practice, the speed to be measured is seldom in exact synchronous relation with the fork. If the target has such a pattern that its picture becomes stationary at each and every 100 revolutions per minute, the speed to be measured may lie anywhere between the century limits, and the fork is unable to make the picture stationary. As already mentioned, Dr. Drysdale has met this difficulty by the use of a conical roller with stroboscopic disc, and this may be a satisfactory solution of the problem for use in the laboratory with a stationary apparatus; but the conical roller device is not portable.

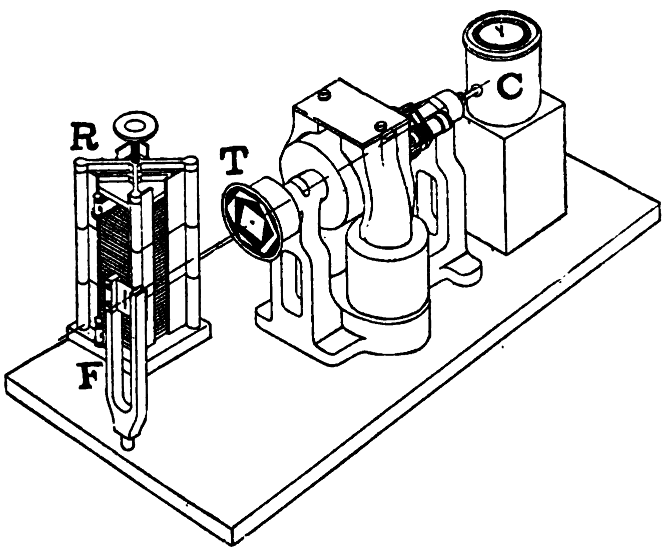


FIG. 5—Calibrating device

The writers have succeeded in arriving at a portable type of stroboscopic fork, which admits of being adjusted in its rate of vibration through a range of about 5% either above or below its mean value, continuously, and without sensibly disturbing the motion. For this purpose a pair of sliding weights grip the sides of the fork friction tight, and can be moved gradually from one position to another within a range of about 7½ inches (19 cm.) by a pair of strings passing over guide-pulleys, and normally slack.

The instrument is shown in perspective in Fig. 8. Its details, in plan, elevation, and end views appear in Fig. 9.

Details of construction. Referring to Fig. 9, the fork *A* is made of a strap of vulcan tool steel 36.7 in. (93.0 cm.) long, 1 in. (2.54 cm.) wide, and $\frac{3}{16}$ in. (0.475 cm.) thick, weighing, without attachments, 1.925 lb. (873 gm.). The over-all length of the fork along its midplane is 18 in. (45.8 cm.). The reason for using so long a fork was to produce a low-frequency vibration, or a fork speed comparable with the speeds ordinarily met with in rotating machinery.

The fork is mounted on a base-plate of cast aluminum by an aluminum clamp with a steel screw $\frac{1}{4}$ in. (0.64 cm.) in diameter. The free ends of the fork carry a pair of thin sheet-steel shutters with slits 0.59 in. (1.5 cm.) long and 0.008 in. (0.2 mm.) wide.

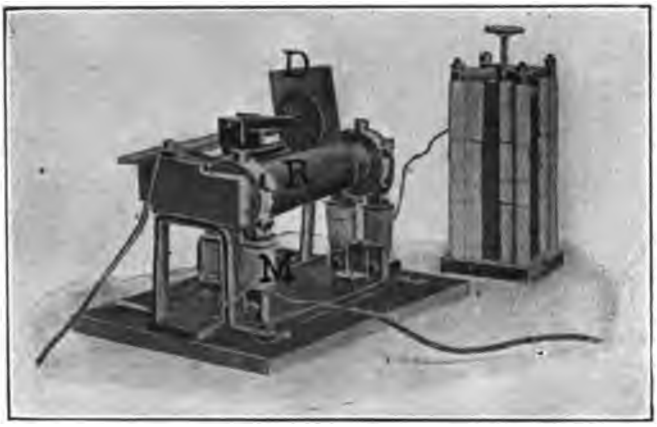


FIG. 6—Roller stroboscope

There are small brass screw adjustments for bringing these slits accurately in conjunction when the fork is at rest, and there are also small brass screw clamps, with copper washers, for clamping the shutters in this position. The fork can be tuned to the required normal frequency by small brass weights clamped on pins set into the free ends of the prongs, near *C*.

The sliders, *B*, are rectangular pieces of cast iron, milled out to travel smoothly over the fork, and closed by brass plates on the outer sides of the prongs. The brass covers are provided with recesses $\frac{1}{8}$ in. ($\frac{1}{3}$ cm.) deep, into which fit bent strips of clock-spring, 1 in. (2.5 cm.) long and $\frac{3}{8}$ in. (1 cm.) wide. These springs rest with their two ends pressing against the outer surfaces of the prongs, and prevent the sliders from moving when the

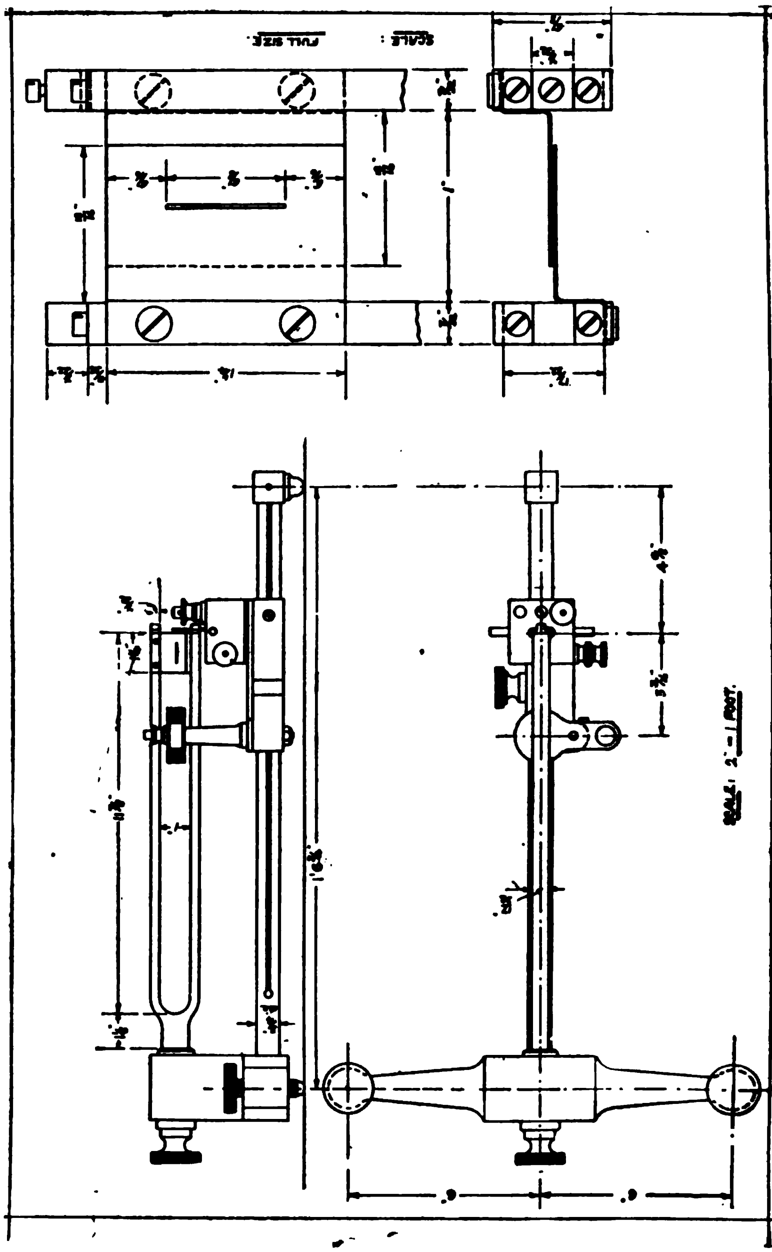


FIG. 7.—Details of Drysdale fork

fork is held upright. At the same time the sliders do not grip the prongs so tightly but that they are readily slid along by strings which are fastened to them. These strings pass over guide-pulleys of aluminum, some on the base and others on the prongs, and are clamped under screws carried by the aluminum wheels *J*, near the apex of the fork. The strings lie normally

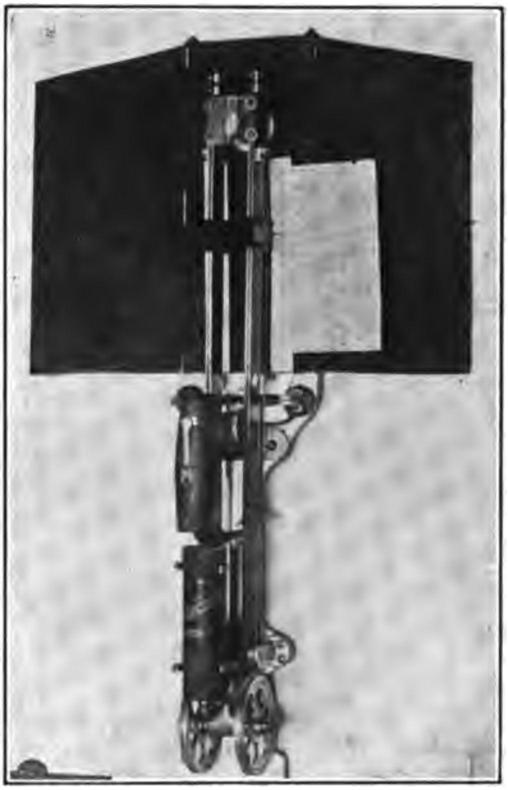


FIG. 8—Perspective view of variable-frequency fork

slack, and vibrate with the fork. Tension is applied in either direction by the hand of the observer on one of the wheels *J*. The wheels are clamped on a common shaft in such a manner that they exert equal and symmetrical tensions on the two strings and pull the sliders along evenly. The sliders carry pointers that move over graduated scales, from which the speed of the fork can be read directly.

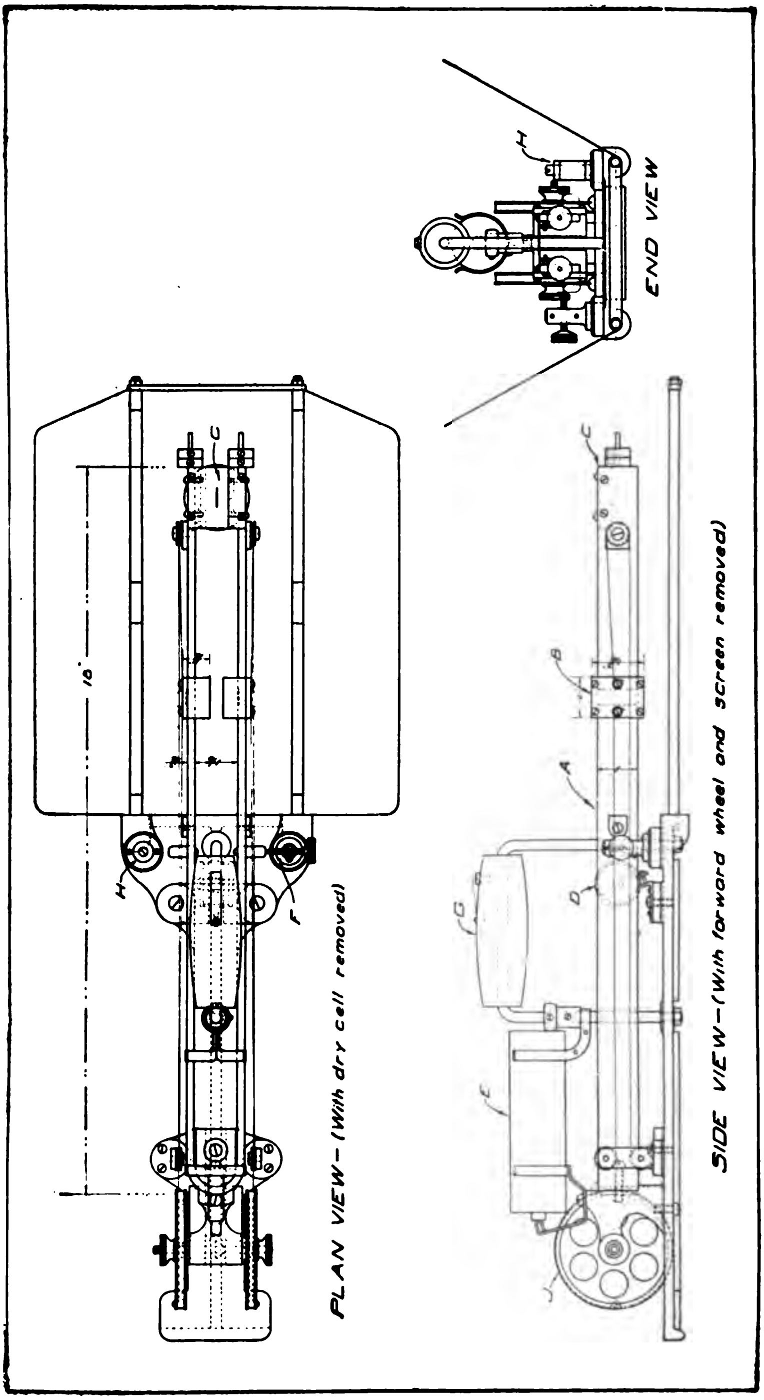


Fig. 9—Details of variable-frequency fork

The fork is driven by the electromagnet, D, held between the prongs in a brass sleeve, mounted on an adjustable aluminum sole-plate. The electromagnet spool carries 15 layers, each of 35 turns of enameled copper wire 0.0165 in. (0.42 mm.) enameled to 0.018 in. (0.456 mm.), and offering a resistance of about 3.25 ohms. There is a very light steel spring fastened to each prong near the electromagnet, and one of these springs is used to open and close the circuit by a platinum-tipped contact, vibrating against the tip of an adjustable milled-head brass screw, F, set in an insulated aluminum split post. The resilience of the contact spring must have no appreciable effect on the speed of the fork, as is easily tested by watching a synchronously rotating target while turning the axis of the fork slowly by the handle. In order to suppress sparking at the vibrating contacts, a spool H, carrying a few feet of insulated german-silver wire, of about 70 ohms resistance, is connected permanently in shunt to the contacts. Current is supplied to the electromagnet from a single dry cell of standard type, having an electromotive force of 1.45 volts, and an internal resistance of about one-third ohm. The average current strength used in operating the fork is about 0.15 ampere. The dry cell, E, is held in spring clips, in such a manner that inserting the cell into the clips automatically inserts the cell into the circuit, or effects the necessary electric connections. The amplitude of vibration of the prongs of the fork is about $\frac{1}{8}$ in. (3.2 mm.) at the slits, on each side of the zero position, or position of rest, which produces a maximum cyclic velocity of about 1 foot (30 cm.) per second at the normal speed of the fork. Since the slits pass each other travelling in opposite directions their relative velocity is about 2 feet (60 cm.) per second, and the duration of each peep through the slits will be one three-thousandth second, or one one-hundred-eighty-thousandth minute. A target rotating at 1800 rev. per min. will only move through one one-hundredth of a revolution during each peep, and since the pitch of the teeth on the outer edge of the target is one-eighteenth of revolution, the blurring of the visual image, due to the motion during the intervals of vision, will only be about one-sixth of the pitch. The blurring is not troublesome if the motion during each peep is distinctly less than one-half of the pitch in the pattern under examination. The higher the speed of rotation, therefore, the greater must be the speed of the slits, either by increase of vibration amplitude or increase of frequency, and the narrower must be the slits, other things being equal. The same result will be produced, however, at high steam-turbine speeds, by using targets of smaller number of teeth in the pattern, so as to increase the pitch.

The instrument is held by the handle, *G*. The handle carries a small contact key, which is closed by the hand grasp, for automatically interrupting the voltaic circuit when the apparatus is laid aside. The weight of the instrument complete as seen in Figs. 8 and 9 is less than 6 lb. (2.65 kg.).

A pair of brass rods support aluminum sheets that shield the observer's eye from extraneous light when looking through the slits. The sheets also carry the scales for reading off the speed of the fork, and they fold over the prongs so as to cover the slits when the fork is out of service.

Process of observing. In order to make a measurement, it is necessary to fasten the target concentrically upon an end of the rotating shaft whose speed is required to be ascertained. Cement, or soft sealing wax, will serve for a dynamo- or motor-shaft. A shaft that runs warm, and has an oily surface, is hard to apply cement upon. In such cases, a metallic spring clip has been used. When neither end of the shaft projects from a bearing, it is difficult to fasten the target on. Sometimes, however, the spokes of the wheels on the shaft will serve as a target. If not, it may be necessary to mount the target on a light auxiliary shaft in bearings, and drive a pulley on the same from the shaft which is without projecting ends, by an endless tape belt, so as to bring the speed of the target into definite relation to the speed of the shaft under test.

The target should receive good daylight illumination. In the absence of such natural illumination, excellent results can be secured from a single 16 candle-power lamp and opaque reflecting shade, supported near to the target, so as to throw on its surface an illumination of about 25 foot-candles (300 meter-hefners).

The observer takes a convenient position facing the revolving target, holds the fork in his left hand, with the prongs vertical, and looks through the slits. If he is sitting, he rests the aluminum foot of the baseplate on his knee. He then moves the wheels with his right hand, until one of the patterns on the target, preferably the external one, comes to a standstill. He then reads the speed from the scale.

Target. After many experiments on different sizes, colors and patterns of target, the writers have selected in preference that shown in Fig. 10, bearing white markings on a black ground. Its diameter is 9.5 in. (24.2 cm.). It is made, with advantage, on paper, with the aid of a stencil, and pasted on a backing disc of cardboard, pasteboard, or sheet metal, for mounting on the rotating shaft. It will be seen that it differs only in minor details from the target indicated in Dr. Drysdale's earlier paper, (Fig. 2).

If the pattern on a rotating target has a positions of symmetry per revolution, and makes n revolutions per unit of time, and

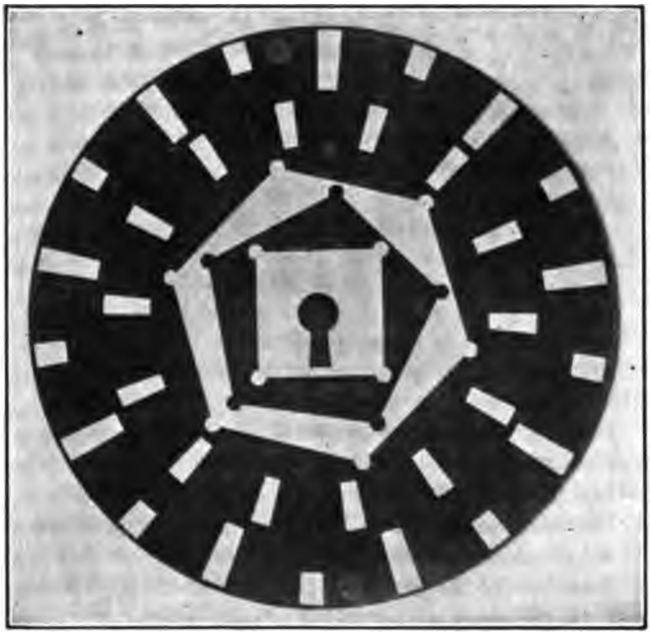


FIG. 10—Target for use with variable-frequency fork

if the speed of the fork's vibration is such that it provides p peeps per unit of time, then the pattern will appear stationary through the fork when $(a\,n)$ and p are in integral numerical relation. Ordinarily, $(a\,n)$ is greater than p; so that standstill occurs in the picture when $\frac{a\,n}{p}$ is any integer. For instance, either a pentagon or a five-pointed star, rotating about its center of figure, has 5 positions of symmetry per revolution. If the fork gives $p = 1800$ peeps per minute, and the speed of rotation is say just $n = 1080$ revs. per min., then $\frac{a\,n}{p} = \frac{5400}{1800} = 3$, an exact integer, and the picture will appear stationary. Moreover, the pentagon will be moving through three positions of symmetry, or 216°, between successive peeps.

The target of Fig. 10 contains a square, a pentagon, a hexagon, a 14-point star, and an 18-point star. The fork has a mean speed giving 1800 peeps per minute. The square, having 4 positions of symmetry, will appear stationary at 450, 900, 1350, 1800, 2250, 2700, 3150, or 3600 rev. per min., that is, at every 450 rev. per min. or quarter of synchronous speed. Moreover, the image of the square will appear doubled, although fainter, at the intermediate speeds of 225, 675, 1125, etc., rev. per min.; that is at every 225 rev. per min., or eighth of synchronous speed.

The pentagon, with 5 positions of symmetry per revolution, will stand still at every 360 rev. per min., or fifth of synchronous speed. It also appears stationary, doubled but less plainly, at every 180 rev. per min., or tenth of synchronous speed.

The hexagon, with 6 positions of symmetry per revolution, will stand still at every 300 rev. per min., or sixth of synchronous speed. It doubles and will stand still at every 150 rev. per min., or twelfth of synchronous speed.

The 14-point star, with 14 positions of symmetry per revolution, will stand still at every 128.6 rev. per min., or fourteenth of synchronous speed.

The 18-point star, or external circle, with 18 positions of symmetry per revolution, will stand still at every 100 rev. per min., or eighteenth of synchronous speed. Since nine of the points are long, and intermediate points are short, the series of 18 will be stationary and clear for even hundreds, and stationary but blurred on the inner edge, for odd hundreds of rev. per min.

The reason for selecting the above described particular set of target patterns is that it includes the following series of integral values for a:

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, and 18. In other words, standstill of some pattern will be produced with the normal fork speed at any half, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, twelfth, fourteenth, or eighteenth of synchronous speed. In addition to this, the speed of the fork can be varied adjustably within a range of 5% above or 5% below normal. This is sure to bring some pattern to standstill at any except very low speeds of rotation. By means of a graphic chart, and a little examination of the pattern, the speed of rotation can be read off directly from the pointers on the sliders. A displacement of 1 mm. (0.0394 in.) corresponds, on the average, to a change in fork speed of about 1.25 peeps per minute, or less than one-tenth of one per cent.

The scale of speed variation with slider displacement is not evenly graduated. The successive intervals correspond to an equation of the second degree. The distance that must be moved for a change of one revolution per minute is about 20% greater when the sliders are approaching their limit near the middle of the prongs, than near their limit towards the end of the prongs. This means that the scale must be prepared from a suitable number of calibrating observations. The simplest way to calibrate the scale is to keep the speed of the rotating target constant, by the control of an observer with an auxiliary fork, and to count the number of revolutions per minute of the image through the calibrated fork, with a stop watch, as the sliders are shifted from point to point along the scale, say 1 cm. at a time.

Applications of the instrument. As pointed out in Dr. Drysdale's papers, the stroboscopic fork is a very convenient instrument for measuring speeds with precision, and particularly for measuring small variations of speed. The device is, in effect, a speed-variation microscope. The instrument is useless when the speed is rapidly varying through a wide range in an irregular manner, except that it gives in such cases ample qualitative evidence of such irregularity. Cyclic variations of speed, as in the hunting of a synchronous motor, if not too rapid, can be measured by observing the angle of oscillation of the target pattern. Variations in the frequency of an alternator, or of slip in a motor, can be observed with ease. There is something fascinating in the pictures presented by the instrument, which are very striking when observed for the first time.

Limits of accuracy in the use of the apparatus. The degree of accuracy of the simple stroboscopic fork is remarkably high, and of the order of one part in ten thousand. The variation of fork speed with temperature is about 0.01 per cent. per degree cent. according to measurements reported.[3] In the fork with adjustable sliders described in this paper, the degree of precision in speed is reduced to some extent, owing to errors in the parallel

3. Electrical Review article, Sept. 1906.

movement of the two sliders, and to errors in reading off their position along the scale. Nevertheless, the degree of accuracy remaining is much greater than is ordinarily needed in engineering measurements. Moreover, the degree of accuracy with which *slow* variations in speed can be observed is as high in the fork with adjustable sliders, as in the simple fixed fork. At 1800 rev. per min., it is easily 1 part in 1800, and it increases in direct proportion with the speed.*

So far as the writers are aware, there is no patent on the method of measuring speeds here described, and it is free to all users.

*The writers desire to express their indebtedness to Dr. Drysdale, not only for the matters appearing in his papers, but also for illustrations and suggestions directly received from him.

Discussion on "The Measurement of Rotary Speeds of Dynamo Machines by the Stroboscopic Fork." Atlantic City, N. J., June 29, 1908

J. B. Taylor: The stroboscopic disc illuminated by an alternating-current arc or incandescent lamp has been used for a number of years to determine the speed of induction motors, synchronous machinery, and other pieces of apparatus. This method of obtaining intermittent illumination is much simpler than by means of the fork described in this paper, and for some purposes gives the desired information with greater accuracy.

The distinction between the two methods is that the fork gives very accurate speed determinations, while the illumination by an alternating-current source of light gives even more accurate relative speeds of apparatus and frequency in alternating-current systems. In operating and testing alternating-current machinery the electrical engineer is more often interested in the relative speeds of generator and motor than in the exact determination of speed referred to the clock. For example, in testing an induction motor it may be desirable to know whether the slip under a given load is, say, 2 or 2.1%, while it is immaterial to know whether the motor is actually running at say 1800 or 1795 rev. per min. For this test the alternating-current illumination gives the slip directly, while the fork would require simultaneous observations on the motor, the generator or the synchronous motor.

When studying pulsation of synchronous machinery or angular lag of synchronous motors, synchronous converters, etc., with variable loads, excitations, and reactances in circuit, the alternating-current arc is again superior to the stroboscopic fork; for while the fork can give general indications of pulsation, it can give no indication of the angular lag referred to.

I have found these stroboscopic discs useful in another way not mentioned in the paper—in the determination of the speed of very light pieces of apparatus which have insufficient power to drive speed indicators or tachometers. For this or any work where actual speed rather than relative speed is desired the fork will be found useful, and I think that the authors of this paper should be thanked for having brought it to such a compact and convenient form.

C. A. Perkins: I have been doing some work with the stroboscopic fork, and any one who will try it in the laboratory will be interested to find how it smooths out characteristic curves, or any curves depending on frequency, to have an accurate device for determining the speed.

I wish to call attention to the range of speed obtained without having any shifting device. Use a tuning fork making thirty vibrations a second, or 1800 per minute, and the speeds given in the first column will be obtained. A fork which makes twenty-five vibrations instead of thirty gives the speeds in the second column, while a fork with twenty vibrations gives the speeds in the third column.

Vibrations	30	25	20
full-speed	1800	1500	1200
one-half	900	750	600
one-third	600	500	400
one-fourth	450	375	300
one-sixth	300	250	200

The first fork gives, without any slider, all the speeds called for in 60-cycle, alternating-current machines.

The method that I have used for observing synchronism is different from that described by Dr. Kennelly, and was suggested to me by the device which I mentioned at the Asheville meeting, for measuring the slip of motors, by means of a disc on the shaft, with a hole or slit in the disc. If such a disc, provided with a single hole, is placed on the end of the shaft of the machine whose speed is to be measured, and if the experimenter stands so that he looks through this hole at the fork, he will have one look at the fork at each revolution. Suppose the shaft to be rotating at a speed of 1800, then the two are in exact synchronism, and the fork will seem to stand still. Now if the motor speeds up five revolutions per minute, he will see the fork apparently make five vibrations per minute. Instead of adjusting the fork, the experimenter counts the apparent vibrations of the fork. They can be counted up to 150 vibrations per minute, so that the one running at 1800 vibrations can be used for all speeds between 1650 and 1950, the one running at 1500, from 1650 down to 1350, and so on. Therefore, without any slider it is possible to use three tuning forks for all speeds in ordinary testing work. At the higher speeds, one hole in the disc is sufficient, but at the lower speeds the fork is seen at such long intervals that it seems to flicker, and it will be necessary to have two or three slots, according to the speed which is to be used. I have used this fork especially for alternating-current work; it is a simple, satisfactory, and inexpensive apparatus for this purpose.

C. H. Sharp: I think most of us are more or less familiar with the various applications of the stroboscopic method to speed measurement, but I wish to express my sense of our indebtedness to Dr. Kennelly and Mr. Whiting for having reduced this method to such a practical and convenient form for actual use.

It is not difficult in a well-equipped laboratory to assemble a combination of tuning forks and rotating discs, or something of that kind, and make it work nicely there, but here is a thing that can be picked up and taken to any place where a test is to be performed, where we merely attach a disc to the rotating element and measure the speed accurately, or measure the slip or variation of speed accurately.

A. E. Kennelly (by letter): It has been found that no target is ordinarily required when the fork is used to measure the speed of alternating-current machines for 60-cycle frequency. It suffices with such machines to illumine the polar projections of the rotor, and examine these through the fork, in order to measure their speed, unless the speed and frequency should be more than 5% in error.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

NOTES ON THE ELECTRIC HEATING PLANT OF THE BILTMORE ESTATE

BY CHARLES E. WADDELL

Under the conditions of modern life electricity is an indispensable adjunct to the successful conduct of an establishment the size of Biltmore House; in this residence, besides the power, lighting and signal service, it is now also used for heating.

For the last two years both the hot water system and the laundry have been operated by electricity. Before entering upon a detailed description of the systems, the reasons for the substitution of electricity for fuel will be briefly stated. Under former conditions, to supply the laundry with steam and to maintain a supply of hot water, it was necessary to keep both a hot water heater and a high pressure boiler constantly fired. To operate the plant required the services of three attendants. At certain hours of every day a portion of the attendants' time was required by other duties; but in the summer months and when the house was unoccupied, their entire time was virtually bestowed upon this very small duty. Anthracite coal, costing approximately $11 per long ton, was used. The difficulty in maintaining an adequate supply, together with the noise and dirt incidental to unloading, and the cost of the removal of the ashes, rendered its use undesirable and very expensive.

The majority of southern hydroelectric corporations furnish power under certain imposed conditions as to peak, load-factor and the like, at approximately 8.5 mills per kilowatt-hour. A study of all the conditions and a review of these facts indicated that economy would result from an abandonment of fuel and the introduction of electric heat.

The plant as it stands has a capacity of 167 kw. and it has thus far fulfilled all expectations as to economy and reliability.

Hot Water System. The hot water system is that common to all large buildings. It consists of a loop system of piping, leading from storage tanks, and so laid out that gravity maintains a constant circulation. As a consequence, the temperature is to all practical purposes uniform throughout the house, and on no line is it necessary to withdraw a quantity of cold water before the hot comes. The stand-by losses are of course excessive, but the comfort more than compensates for the additional cost. Two storage tanks are employed, each with a capacity of 500 gal. Into the top of one of these cold water from the main enters; from the side and bottom a loop of three-inch pipe is taken out and carried to the heaters which are located some twenty-five feet lower. The heaters are the lowest point of the system.

Heat was formerly supplied by a type of heater, which closely resembled a self-contained vertical tubular boiler. To maintain an adequate supply of water at a temperature of 200° fahr. required a fuel consumption of ten pounds of anthracite coal per hour. Tests of long duration showed this to vary but little.

The electric heater is a cylindrical steel tank, three feet in diameter by five long, containing twenty flues arranged in two concentric circles, and the whole closely resembling in appearance a miniature horizontal tubular boiler. Each of the twenty flues contains a heating element of 5 kw. capacity; consequently the total capacity of the heater is 100 kw. The connecting terminals are brought out at one end of the tubes; at the other end a nut holds the elements in place. The withdrawal of the element is accomplished by simply removing the nut.

The electric heater is installed beside the coal heater and the two are provided with valves so that either or both may be used as occasion demands.

Electricity is supplied in the form of a three-phase, 60-cycle, alternating current at a potential of 230 volts. A switchboard panel is installed immediately in front of the heater and the elements are grouped thereon in three banks, each bank connected to phase, a feature of great value in balancing the load on the transformers. The power-factor of the elements is unity. This was determined by observing the current consumption first on the direct-current circuit and then on the alternating, the amperage in each case being the same.

The form of the hot water heater and the uniform rate of fuel consumption led to the conclusion that its efficiency was considerably higher than the ordinary steam boiler, and probably approximated 65 per cent. Assuming the coal to have a heat value of 14,000 B.t.u., the effective value would be 9100 B.t.u.; and since 1 kw-hr. is equivalent to 3412 B.t.u., it appeared that an input of 26.6 kw. would be an equivalent.

The approximation was so close that when the electric heater was placed in service, 30 kw., were applied; and with the excep-

FIG. 1—Fuel and electric hot water heaters

tion of a few hours in the late evenings when 5 or 10 kw. more are necessary, or the early mornings when not so many are needed, this input has been varied but little.

The energy input in any apparatus is divided into useful work and heat losses; in heating apparatus since the entire work is the production of heat, where the elements are totally immersed, the efficiency theoretically should be 100 per cent.; this is modified to some extent by the heat absorbed by the material of which the element is made.

In order to determine the actual working efficiency of the above heater, its piping was disconnected from the system, cold water was introduced, and the valve so adjusted that with a fixed input of 40 kw. the water discharged was at constant

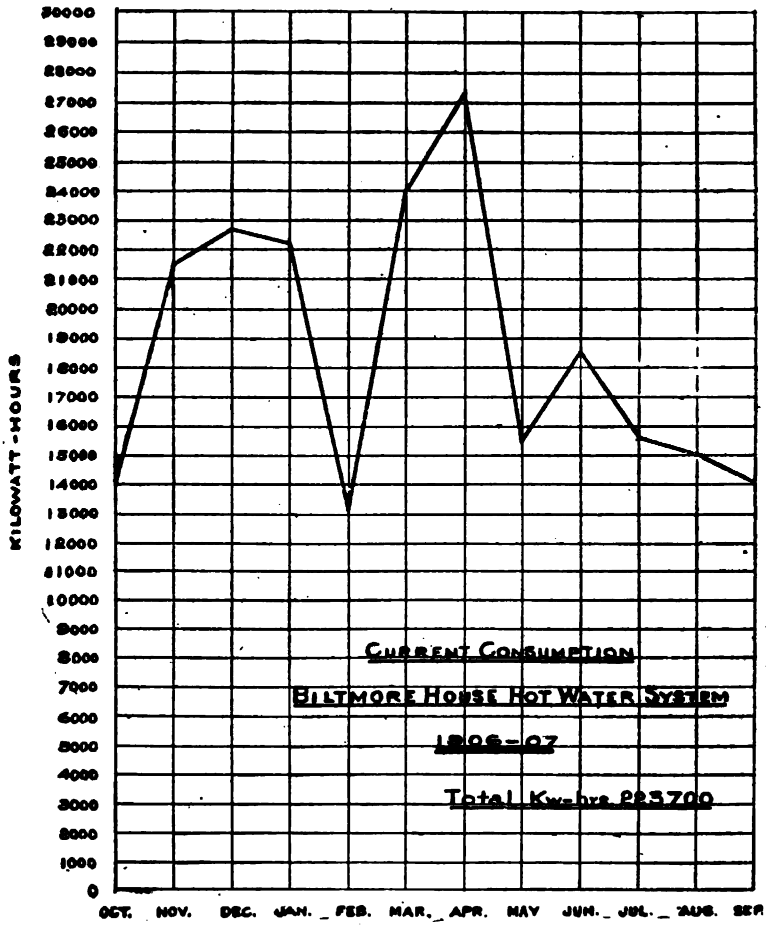


FIG. 2

temperature. The discharge was weighed, the input meter read at the start and conclusion of the test, and from these data the net efficiency found to be approximately 85 per cent. That is to say, 85 per cent. of the input becomes available and effective, in the hot water system; the other 15 per cent. is lost in radiation from the boiler shell, through the tubes, and from the attachments and piping. The author is of the opinion that the recorded efficiency is too low and may be considered as ultra conservative. Nevertheless it represents the efficiency of the plant under everday working conditions, and is not a test under artificial conditions, such as electric apparatus is often subjected to and which bear scant relation to working conditions.

The water at Biltmore contains a number of carbonates, causing boiler flues to form scale and incrustations rapidly and to an excessive degree; and with all steel piping which is subjected to a cycle of temperature change there is a continuous struggle to remove this coating. In the light of experience, although it would materially increase the cost, the use of copper flues instead of the iron ones now employed seems a justifiable expense. With a flue that would not retain scale, the formation of scale on the shell would be in the nature of additional heat insulation and would be beneficial rather than otherwise.

Ordinarily the deterioration of electric heating elements appears to be rapid; 10,000 hours is seemingly the maximum guarantee to be had. In the case of an element employed in heating water, where the element is at all times submerged, the maximum attainable temperature difference is but 180° fahr. and the deterioration is nothing like so rapid as in other classes of service.

Speaking in the dual capacity of purchaser and seller of power, the writer does not hesitate to say that electric heating for hot water service is the most satisfactory and profitable load to be had. Peak loads are the rare exception; close regulation is non-essential; and momentary interruptions to service are of no importance; and even in prolonged shut-downs the slow thermal change of the liquid is such that ample time to start the auxiliary fuel plant is afforded.

Fig. 2 is a chart showing the monthly current consumption for a year; 20,000 kw-hr. per month is considered normal. When less is recorded the consumption was purposely curtailed in order to keep the total current for the estate within the contract allowance.

The cost of the fuel heater, complete, installed, was about $350. The cost of the electric heater, complete, installed, and including switchboard, foundations, and pipe connections, was approximately $1200.

LAUNDRY EQUIPMENT

The electric equipment installed consists of:

1 Dry room heater, capacity approximately 16 kw.
1 Mangle, 48 in. by 16 in., capacity 8 kw.
4 4-iron stoves, each with a capacity of 2 kw., total 8 kw.
1 Steam generator, capacity 35 kw.
Total capacity 67 kw.

From the main switchboard current is conducted to the

FIG. 3—Rear view of 100 kw. hot water heater

laundry by three 500,000 cir. mil cables which terminate in a three-wire cabinet, the capacity of the panel being 1000 amperes. All conductors are run in galvanized conduit, the most substantial construction is followed, the aim being to secure an installation comparing favorably with steam apparatus in simplicity and durability. All laundry apparatus works interchangeably on direct or alternating current.

The dry room with a cubical contents of 640 feet is provided with three heating elements in the form of plates which are supported on porcelain insulators resting on the floor. Connections from the controlling switch box are made through asbestos covered wire and mechanical, in preference to soldered.

FIG. 4—Dry room. showing clothes racks and air flue

joints are used where possible. The dryer is equipped with the ordinary form of vertical clothes racks travelling on rollers. To accelerate the process of drying an 18 in. galvanized iron flue leads from the top of the room to a nearby chimney. In laying out this apparatus it appeared feasible to supply only heat sufficient to maintain circulation; the theory being that rapid passage of warmed air would more or less mechanically exhaust the moisture.

In this connection it may be of interest to show how the equivalent heating capacity was determined. Originally the room was equipped with 108 sq. ft. of radiation in the form of 1 in. pipe. The steam pressure was kept at 60 lb. gauge; representing a temperature of 309° fahr. The temperature of the air in the dry room was usually 185° fahr., a difference of 124° fahr. Assuming that 1 in. wrought iron pipe radiates 2.9 B.t.u. per sq. ft. per degree difference of temperature; and since 1 kw-hr. is equivalent to 3412 B.t.u.; we have:

$$\frac{2.9 \times 124 \times 108}{3412} = 11.4 \text{ kw.}$$

Practically 12 kw.; a capacity on which all estimates were based. The discrepancy between the calculated and installed capacities is due to our use of certain elements on hand that would otherwise have been idle; and the greater capacity appears to facilitate the work.

The following is the average weekly performance, the dryer being used three days, and each day listed separately for comparison.

Monday, March 30, 1908. General household wash, such as shirts, underclothes, stockings, table linen, towels, sheets, etc.

Number of hours used	10.5
" " articles dried	339
Weight " " dry, lb	103
Average temperature	101° fahr.
Number of lb. water expelled	84
Kw-hr	124

lb. water expelled per kw-hr	0.68
lb. clothes dried " " "	0.83
Number of pieces " " "	2.73

Thursday, April 2, 1908. Used for drying 18 shirts only. Shirts had been starched.

Number of hours used	4
" " articles dried	18
Weight " " dry, lb	9
Average temperature	110° fahr.
Number of lb. water expelled	12
Kw-hr	68.4

The heater was turned on at 8 a.m. and in empty state reached working temperature in one hour. Clothes were put in 1.5 hours after current was turned on; the mere act of drying, therefore, required 33 kw-hr.

Friday, April 3, 1908. Second general wash.

Number of hours used	7.25
" " articles dried	276
Weight " " dry, lb	143
Average temperature	110° fahr.

FIG. 5—Electrically heated mangle

Number of lb. water expelled	182
Kw-hr	125
lb. water expelled per kw-hr	1.45
lb. clothes dried " " "	1.14
Number of pieces " " "	2.20

Clothes ordinarily enter the dryer at a temperature of 83° fahr., having previously been raised to a high temperature in the process of boiling and washing.

The steam mangle formerly used was converted to electric service by providing the rotating drum with heating elements.

Connection with the circuit is effected by means of a 3-ring collector and carbon brushes. Three degrees of heat may be had, the maximum input is 8 kw. and the heating intensity is 475 watts per sq. ft. of surface. The performance of this machine is far more satisfactory than when used with steam; especially gratifying is the absence of leaky stuffing boxes.

The record of an average day's work is given below:

Current turned on mangle at 6.30 a.m.

Mangle started to work at 8.30 a.m., stopped at 2.30 p.m., off 45 min. for lunch; off 30 min. to cool; total hours current was on, 6.45.

Amperes, 45; volts, 118.

Two girls working. Articles mangled were: towels, table cloths, napkins, sheets, bed spreads, pillow cases.

Total weight articles in lb	221.
" square feet mangled	12,256.
" number of pieces	471
" kw-hr	35.8

All pieces were passed through twice, and many pieces three times, this accounts for the large surface area. The articles were cotton and linen.

The cost of equipping this mangle, including freight, drayage and installation, was approximately $175.

The diversity in weights, shapes and uses of the sad irons in this laundry led to the selection of electric stoves in preference to electric irons. Experience has taught that such claims were given undue consideration, and I am now of the opinion that an equipment of electric irons weighing from 7 to 12 lb. would be preferable. For heating very special shaped irons, used on laces, etc., one stove might prove necessary. A consideration entirely apart from the merits of the irons has led to their partial abandonment, and that is that with the advent of the electric apparatus the temperature of the laundry was lowered to a degree where the ironed clothes would not " air " properly, and it was found necessary to keep the coal stove going to overcome this obstacle. It appears that where clothing is at once stored, and not again immediately used, that this " airing " is essential to their preservation. With the coal stove working the use of the electric stoves was in the nature of a waste.

Below is given the record of a day's ironing using the electric stoves:

Two girls worked six hours each.
219 pieces ironed; articles were stockings, handkerchiefs, towels, napkins, pillow cases, petticoats, skirts.

Gross weight, damp, lb	63
Net " dry, lb	41
Kw-hr	24

It required 40 minutes to bring stoves and irons to working temperature. An iron heats in 8 minutes after being returned to the stove, and will hold sufficient heat to iron from 4 to 7 minutes, depending on the dampness of the article and the material. To properly iron a handkerchief requires 7 minutes, a bath towel 4 minutes.

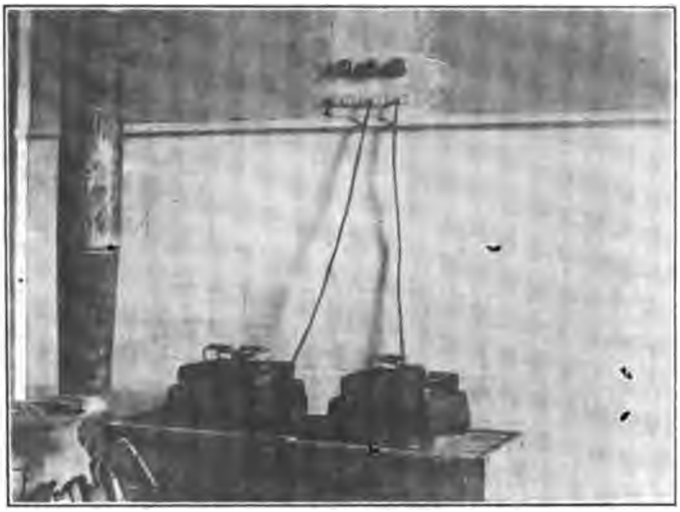


FIG. 6—Electric stoves for sad irons

The foregoing data are submitted simply as an illustration of actual performance, and represent average results; they are given in detail that others working along the same line or being confronted with new problems may glean some help from our experience. When the plant was begun we quickly realized the dearth of available data; and I believe that if all experimenters will publish the results of their investigations, facts will be gathered from the mass of testimony which will result in improved and more efficient apparatus.

Allusion has been made to the use of electric irons versus electric stoves; in connection with the former attention is called to the matter of cords and attachments. These are the weak points in this class of apparatus. The cords get damp and short-circuit, the terminals break loose, and the insulation frays off.

FIG. 7—Steam generator and laundry tubs

For small irons and light service the existing practice is fairly good, but in heavy work, to insure success, a more substantial equipment must be designed.

By far the most interesting piece of electrical apparatus at

Biltmore is the steam generator. With the abolition of steam service some method of boiling the clothes had to be provided. Of the several suggested and tried forms, the one in use seems best suited to the requirements. In the winter when steam heat is on the house, it is in the direction of economy to use steam from the mains. For nine months of the year heat must be secured elsewhere. Boiling the clothes is an essential process. To retain intact the steam apparatus was an obvious desideratum; to provide supplementary electric apparatus introduced com-

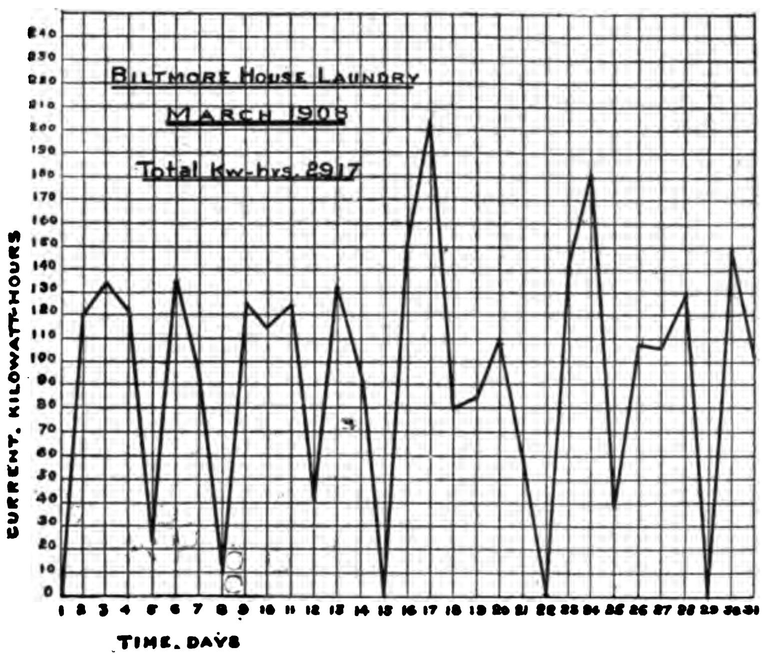


Fig. 8

plications; and a compromise was effected by generating steam with electricity, piping the generator into the steam mains, a series of valves rendering the two sources of heat interchangeable. The steam generator consists of a group of five 3-in. vertical pipes. Around the pipes the heating elements are placed. The pipes are interconnected at both top and bottom; the top is provided with a steam dome; and the whole is equipped with water column, steam gauge, pop valve and inlet water regulator. The function of the regulator is to keep the water level in the boiler constant. Feed water is taken from the hot water mains. At the base, and integral with the frame, are five switches, each controlling a 7 kw. element.

Steam at practically zero pressure is conducted to five tubs and there discharged through perforated pipes located in the bottoms. The tubs are made of porcelain and contain about 2 cu. ft. each.

When new the generator was tested to determine its evaporative efficiency, this was found to be between 95 and 100 per cent. The appliances at hand were not adapted to precise work, but the result is not very far wrong in my opinion. The test was made by bringing the contents of the boiler to the boiling point, marking the height of the water on the gauge glass, evaporating a given weight and ceasing when the water in the boiler was level with the starting point. The meters were read at start and finish, and the input determined. The varying barometer and the inaccuracies of the thermometers introduced error, and it is by no means certain that the meters were exactly right, although they were new and of the highest grade.

In service the performance is as follows:

92 lb. water in tub.
7 lb. linen " "
To raise to boiling point requires 10 kw-hr.
Clothes are boiled 20 min. and current consumed is 4 kw-hr.
Total kw-hr. per batch.........................14

Digressing from the subject, it seems to the author that this form of steam generator is admirably adapted to the service of train heating, where steam and electric locomotives are alternately employed. Worked in connection with a return system of piping, water storage only sufficient to supply leakage would be necessary. The generator being located on the locomotive the increase in weight on the drivers would be an advantage. The low cost, and the simplicity of the apparatus together with the fact that it would fit existing equipment should, I think, render an experiment worth while.

Plate Warmer—In addition to the two large classes of service that have been described, there is installed in the butler's pantry an electric plate warmer. This piece of apparatus is in the form of two shelves, each 24.5 in. by 43 in. and each with a rated consumption of 840 watts; an equivalent heating effect of 0.8 watts per square inch of surface. Each shelf is provided with its own switch, the ordinary double-pole indicating snap switch is employed for control, the wiring is of the fire-proof form of insulation, and the current supply is taken from a nearby lighting main. The lighting system being designed for operation on either the alternating bus-bars or the direct-current storage battery bus-bars, it follows that, like the laundry, the plate warmer works interchangeably on the two classes of service.

At the time of purchase this type of heating apparatus sold for approximately $6 per square foot.

Conclusion—As was aptly pointed out in an editorial of a representative technical paper not long since, electric heating has suffered from the fact that its economic possibilities have usually been considered from its thermal unit value; and the lesson to be drawn from the Biltmore installation is that a careful analysis of all the conditions may disclose the fact that while theoretically a disparity exists, nevertheless economy may accrue due to the better operating conditions.

Enthusiastic advocates of electric heating are to-day making broad claims which in a measure mislead the uninitiated; this in the author's opinion should be discouraged. The prices at which electric power is generally sold and the state of the heating art do not as yet admit a wholesale and unreserved usurpation of the heating field; and it is a question whether this state ever will be reached. One thing, however, is certain, and that is that Utopian dreams and unsubstantiated claims are going to do much harm and no good; and all projected heating installations of any magnitude should be accorded careful attention and considered in the light of an engineering undertaking, not merely as a matter of domestic or commercial installation.

We have found that the standard forms of enclosed fuses when continuously worked at or near their rated capacity on heating apparatus rapidly deteriorate, failing without apparent cause. For this fact I have no explanation to offer.

Experience leads to the conclusion that for heavy heating work a number of auxiliary appliances accepted as standards in lighting work will have to be either remodeled or abandoned. The temperature at which heating elements work renders the use of solder undesirable; in a number of instances that have come under our observation the terminals have melted off. The use of fire-proof or asbestos covered wire is to be preferred to rubber, even in conduit installations.

Where cords are required it would appear better construction to use flexible armored cable. For stationary apparatus the switching devices should as far as possible form an integral part of the apparatus; and where necessary to separate the two, connection between them should be made through conduit, and both switch and heating element be arranged to mechanically unite with the conduit. In the majority of places where electric heating apparatus is employed water or steam is present, and for this reason the switching devices should be accorded special attention. The open knife switch is altogether unsuitable; the enclosed knife switch some, but not much, better; and the oil switch entirely out of place. A little mechanical ingenuity bestowed upon these details would effect a decided advance in the art and would eliminate one source of trouble.

Discussion on "Notes on the Electric Heating Plant of the Biltmore Estate." Atlantic City, N. J., June 29, 1908

Percy H. Thomas: This paper is a little out of the ordinary, but the subject which it treats is well worth the attention of light and power men, as indicating how under certain conditions additional load may be obtained. I think the main lesson to be taken from what Mr. Waddell says, is that it is necessary to treat such matters as engineering problems when dealing with electric heating on a large scale, just as in the case of the boiling of water on a large scale in steam-electric plants. The heating of tea kettles and curling irons can be handled satisfactorily without special engineering training, but when large quantities of water are to be heated by electrical means of any kind it is necessary to treat the case as an engineering problem.

Elmer A. Sperry: Will Mr. Waddell please give us the details of his flash boiler?

Charles E. Waddell: The boiler is made of five 3-inch pipes, each six feet long; around each pipe a heating element is wound. The elements are externally protected and thermally insulated, with metal jacket and dead air space. All five tubes connect together at the top, forming a steam header. Water, from the hot-water system, enters at the bottom of the tubes, the quantity admitted being controlled by an automatic regulator the function of which is to maintain the water-level at a fixed point. The boiler is also provided with a low-pressure safety-valve, the discharge from which is conducted into a nearby waste pipe. In operation the device is cleanly, noiseless, and automatic.

John H. Finney: At what price must current be purchased in order to compare with fuel—anthracite coal, for instance?

Charles E. Waddell: Tests on the large steam heating boilers at Biltmore have demonstrated that under normal working conditions their efficiency is about 50 per cent. Assuming that a pound of anthracite coal has a theoretical heating value of 14,000 B.t.u., and allowing an efficiency of 50 per cent., the effective value would be 7000 B.t.u. A kilowatt-hour is practically 3500 B.t.u., hence two kilowatt-hours are equivalent to one pound of coal, assuming of course, that the kilowatt-hour is delivered at 100% efficiency.

Anthracite coal with us costs from $10 to $11 per long ton, virtually one-half cent a pound. To be on a parity, two kilowatt-hours would have to cost one-half cent, hence at a rate of one-fourth cent per kilowatt-hour.

Taken on the whole this is not altogether a fair comparison; for while it establishes the physical equivalent under working conditions between fuel and electrical energy, it does not take into account the time-element and stand-by losses, both of which are important factors in the economy of any plant.

Where the actual use of heat is a small percentage of the total time, entailing as a consequence large stand-by losses; where the service is intermittent; or where the fuel plant is small and the item of attendance large in proportion to the service, the cost of electricity could easily be two or three cents per kilowatt-hour and still effect economy.

To compete successfully with fuel in plants of magnitude—our house-heating plant for example, where the steam boiler capacity is some four hundred horse power—electrical energy at from three to five mills per kilowatt-hour would in all probability be equivalent to coal at $10 per ton.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 30, 1908.

MEASUREMENTS OF LIGHTNING, ALUMINUM LIGHTNING-ARRESTERS, EARTH RESISTANCES, CEMENT RESISTANCES, AND KINDRED TESTS

BY E. E. F. CREIGHTON*

During the past year investigations have been continued in the study of lightning and the operation of lightning-arresters on transmission lines. Another effort was made to supplement laboratory studies with experimental measurements on transmission lines. Two lines were chosen well up in the Rocky Mountains of Colorado as offering the greatest facilities both from the interest of the managers and the frequency and severity of lightning storms. New types of apparatus were developed for measurements and new data were collected. The object of this paper is to describe briefly the instruments and methods used in the measurement of duration, potential, current, frequency, and the theory and practise of lightning protection and earth connections with data collected during two years of study; also resistance measurements of cement under the heating effect of dynamic current, and comments on the action of lightning-arresters.

The scope of the work is represented by the following index of subject-matter:

* The writer wishes to acknowledge his indebtedness to Mr. J. A. Clay, superintendent and operating engineer of the Animas Power & Water Co., for many courtesies in the installation of the apparatus, and for subsequent auxiliary reports; to Mr. W. N. Clark for courtesies extended while observations were being taken on the high-tension lines of the Pueblo & Suburban Light & Power Co.

Lightning potential.
Apparatus for measuring lightning potential.
Lightning current.

SUBDIVISION OF FREQUENCY

Frequency of recurrence.
Frequency multiple stroke.
Natural frequency of discharge.
Very high frequency.
Quantity of lightning { *fuse apparatus* / *ballistic apparatus.* }
Movement of charge on parallel wires.

MISCELLANEOUS OBSERVATIONS

Pueblo and Suburban Light and Power Company.
Animas system.
Lightning recorder.
Records of discharges.
Lightning alarm.
Equipment for study.
Note on choke-coils.
Experience with a grounded phase.
Direct stroke of lightning.
Wooden versus metallic cross-arms.

GENERAL COMMENTS ON THE ARRESTER EQUIPMENT OF THE ANIMAS COMPANY

Location of arresters.
Characteristics of the gap aluminum arrester.
Lightning alarm and the fuse.
Aluminum arresters for direct currents.
Temporary and permanent critical voltage of film.

EARTH CONNECTIONS

Methods of tests of earth resistance.
Pipe earth resistance per foot of depth, Fig. 21.
Effect on the resistance of varying the distance between pipes.
Treatment to improve earths.
Multiple pipe earth connections.
Animas earth test.
Variation of resistance with depth.
Time resistance variation after salting.
Measurement of resistance between pipes and groups.

Measurements between sub-stations.
Measurements of resistance of tree, pole, and railroad earths.
Earths carrying dynamic current.
Form of pipe earth recommended.
Station grounds, resistance factor.
Station grounds, inductance factor.
Station grounds, permanence factor.
Lightning conductors for protecting buildings.

CEMENT AS A RESISTOR

Effect on resistance of cement of various proportions of sand.
Change in resistance with age.
Behavior of cement resistors on constant potential circuits.
Effect of moisture on resistance.
Conductivity at high temperatures or pyro-conductivity.
Change from moisture conductivity to pyro-conductivity.
Concrete as a resistor.
Summary and conclusions on concrete resistance.

CHARACTERISTICS OF LIGHTNING

Before a lightning-arrester can be designed along logical lines the characteristics of the discharge which may pass through it must be known. A complete analysis of lightning phenomena on electrical transmission lines has been given by Dr. Steinmetz.* This analysis is necessary to a thorough understanding of the theory of the subject.

In considering the design of lightning-arresters, a brief classification based on the effects of lightning may be made as given below. The principle factors involved are:

1. Duration of the surge of lightning.
2. The potential values of the lightning.
3. The maximum current discharge rate.
4. The natural frequency of the lightning.
5. The quantity of electricity in the lightning stroke.

In considering the choice and operation of arresters for a transmission line, the most important of these factors is the duration of the surge. These factors will now be discussed in more detail.

1. *Duration of lightning.* Lightning from an external source (cloud lightning) is usually of very short duration. Measurements made during the summer of 1907 in Colorado, gave a

* PROCEEDINGS A.I.E.E., March 1907.

range of 0.04 sec. to 0.0001 sec. Cloud lightning has been known to continue for longer than one-half a second in rare cases. Lightning from an internal source (accidentally grounded phase, switching, etc.) often continues over a period of several minutes, or even several hours.

Lightning frequently recurs in successive strokes. A num-

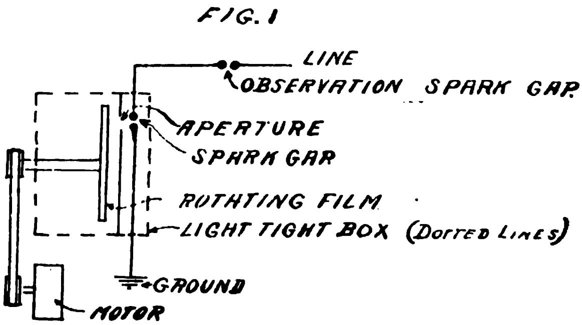


FIG. 1.—Revolving film duration apparatus

ber of measurements were made on an idle line which gave as high as seven separate discharges in one second. In the lightning-arrester these multiple strokes give the effect of long duration.

The duration apparatus. Two different pieces of apparatus were used to measure the duration of lightning. They are shown

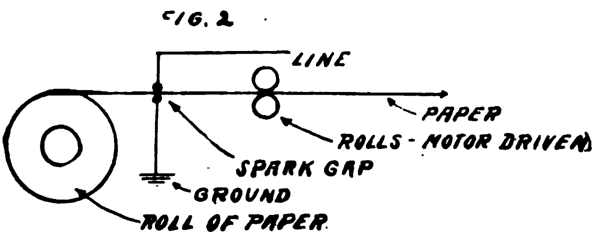


FIG. 2.—Moving tape duration apparatus

diagrammatically in Figs. 1 and 2. For very short duration the apparatus shown in Fig. 1 was used. This apparatus consisted of a spark-gap in front of a rapidly revolving photographic film. Figs. 3, 4, and 5 are records from this machine; they show several different discharges which are made to fall on an unexposed portion of the film by moving in the aperture to a lesser radius on the film. Knowing the speed of rotation of the film, the duration of the discharge was measured. Calculations were made on 36 discharges. Nearly all of the storms that caused the discharges were distant from the station. This may partly account for so many short durations. There were two strokes expressed in hundredths of a second, seventeen in

Fig. 3.—Record from revolving film duration apparatus. This shows one multiple discharge consisting of eight single discharges marked (a) and one single discharge marked (b)

thousands of a second, and sixteen in ten-thousandths of a second. Besides the duration and multiple strokes, these exposures show frequencies of the order of the line frequency. Each exposure is divided into a broken line which represents the frequency of alternation of the discharge. This frequency, about 3000 cycles per second, was further analyzed into a higher frequency by the lightning frequency meter to be described later. Three thousand cycles is beyond the frequency that can be measured by an oscillograph. Where several segments of a circle of the same radius are shown (Fig. 4), multiple lightning strokes occurred; these strokes occurred in such rapid

Fig. 4.—Record from revolving film duration apparatus showing six multiple strokes marked *a*, *b*, *c*, *d*, *e*, and *f*. The small dots at the side of most of the exposures are ink marks to emphasize the markings of the natural frequency of the discharge for fear they might not show up in the usual process of reproduction. This record is unusual in the number of multiple strokes

succession that they appeared as one to the eyes focused on the observation spark-gap.

Fig. 5 is the only record of a discharge that did not show a natural frequency of oscillation. This may have been due to earth resistance being exceedingly high under the line where the lightning charge was set free. A fuller explanation is attempted later.

For the measurement of longer durations of lightning, the paper tape apparatus shown in Fig. 2 was used. The tape was drawn through a spark-gap between line and ground at a uniform rate. This apparatus attached to an idle line showed multiple

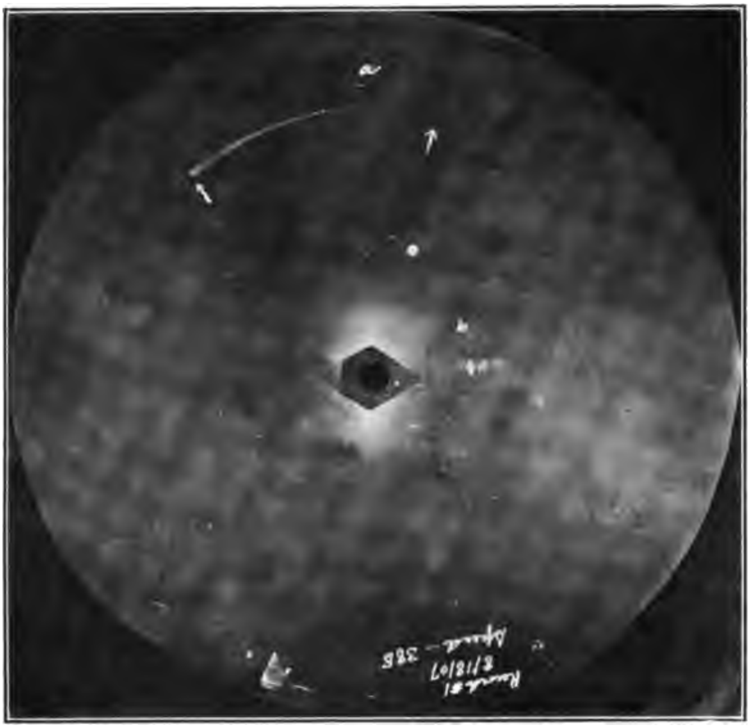


FIG. 5.—Record from the revolving film duration apparatus showing two single discharges. Discharge (a) is the longest one recorded. If there are any natural oscillations the speed of the film is too low to show them

strokes; in several instances, as many as four strokes were distributed over one second. In these multiple strokes the successive discharges could be detected by the ear. It usually produced a rattling sound. Without the apparatus the noise might have been attributed to echoes. Records of multiple strokes and duration as given by the tape will be shown later in this paper.

2. *Lightning potential.* In cases of direct strokes from the clouds to a transmission line, the potential at the nearest insulator builds up so rapidly that even the small inductance of the straight line wire presents a relatively high impedance to the flow of the electrical charge along the wires, away from the point, and consequently it spills over the insulators and down the poles to the ground. In this extreme case a lightning-arrester situated

FIG. 6.—An accidental discharge which passed through the right forearm from the wrist to the elbow and out through an arc to an iron support. This produced complete paralysis of the forearm which lasted several hours. The injury was painless except for the after-effects of the surface burns

some distance away will give no protection to the point struck. If the electrical charge can be prevented from jumping around the insulator by high dielectric strength or overhead ground-wire the charge travels to the nearest lightning-arrester. During this movement it loses greatly in potential and somewhat in natural frequency. In every case of induced static charge from the clouds, lightning potential on the line is always greatest directly under the cloud that is discharging. A number of cases were observed last summer in Colorado when a storm was over an unprotected station about three miles from the main sub-station in which the lightning jumped three and one-half inches over switch bushings at the unprotected station instead of being discharged by a gap set at 0.4 in. (one-eighth as large) at the main sub-station.

If the lightning potential is due to an internal surge of electrical energy between static and electromagnetic energy, then the high potential will exist across the junction point of the parts of the circuit acting as condenser and reactance-coil respectively. This may for example, be, one coil or all the coils of a generator or transformer.

Apparatus for measuring potentials. Practically the only apparatus which indicates the potential of lightning of brief duration is the well known needle-gap. A needle-gap without series resistance would short-circuit the dynamic potential and therefore could not be used. The use of a reasonable resistance in series with a single needle-gap affects its spark potential but slightly even for high frequencies. The electricity travels along the resistance and throws the static stress on the needle-gap and produces a spark. The volume of spark which takes place decreases as the resistance increases. Since it is necessary to record this spark the resistance must be kept at least low enough to permit this. As an example of the effect of resistance on the relative spark potential at high frequency the following is given: two needle-gaps placed in parallel, the first set at 1 in. having no resistance, and the second having two 8 in. rods with carborundum as a base, known as 50,000-ohm rods (actually less at high potentials). The second gap would not spark when set on 1 in. but would, without fail, spark simultaneously when set at 0.9 in. The potential, obtained from a leyden jar and static machine, had an initial value of about 60,000 volts, was very suddenly applied, and had a frequency of about two million cycles per second. At 60 cycles the spark potential of the needle-gap was not affected by this series resistance. This condition of high frequency is probably more severe than will be met on a transmission line.

One needle-gap never actually measures lightning potential unless the applied potential should happen to be equal to the spark potential. If a needle-gap sparks it shows the pressure reached its spark potential but it may have gone very much higher. By using several gaps in parallel the potential may be measured with a rough accuracy depending upon the number of gaps in parallel and the differences in their setting. Fig. 7 shows diagrammatically part of such a lightning potential meter.

In each circuit is a fuse, a needle-gap, and a resistance limiting the dynamic current to about one-half ampere. In operation the impressed potential must be between the largest gap that sparked and the next one above. Since the gap must be set after each lightning stroke, the form of the meter is modified to give a measurement of several successive strokes, to record the time, and to give automatic resetting. Fig. 8 shows one leg of this automatic resetting device.

FIG. 7

LIGHTNING POTENTIAL RECORDER

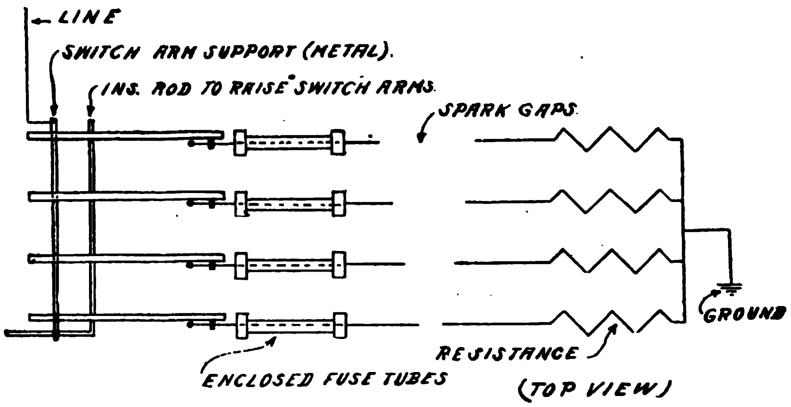


FIG. 7.—Plan of lightning potential recorder

In this leg the gaps are all equal. From the switch arm a thread is run to a pen which draws a line on a paper tape moved by clockwork. This records the exact time when each gap sparks. Since a lightning recording device can be placed on each arrester, the combined results of the two will show the relative efficiency of the arresters for each discharge. For example, the needle-gap of the potential recorder may be set on 2, 2.5, 3, and 4 times normal line potential. To get the proper operation of the potential recorder care must be taken in its design to avoid producing the effect of a grounded phase by the arcing of one phase only.

3. *Lightning current.* The maximum value that the lightning

current may take has an important bearing on the design of the arresters. Until recently it was found necessary and expedient to install some resistance in the arrester circuit to limit the dynamic current which usually follows the lightning discharge. This resistance limits also the lightning discharge current, and by its ohmic drop ($I R$) prevents the lightning potential from decreasing rapidly.

If the lightning discharge current is limited by ohmic resistance it is easy to calculate what current can discharge at double line voltage. Double voltage is usually within the limiting safe

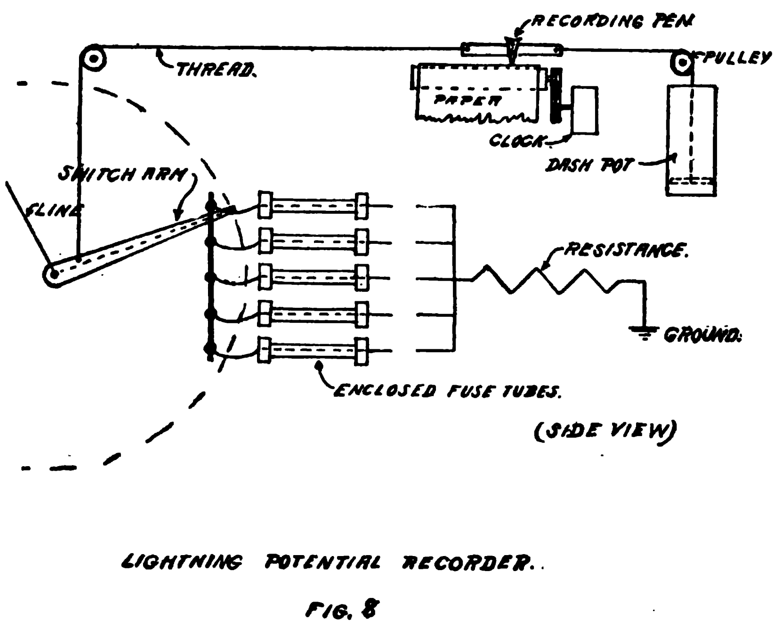


FIG. 8.—Elevation of lightning potential recorder

value. Such a comparison of arresters gives their relative values of protection against lightning.*

The actual measurement of the lightning current is usually more difficult than the measurement of the high frequencies. Several conditions will be outlined here. Since concentrated capacity and inductance are used in the laboratory, these equations are convenient to use here.

* The time constant or natural frequency enters as a factor. A large time constant of the lightning allows of higher resistance in the arrester circuit.

1. In any circuit containing a low resistance, what is the current per volt of impressed electromotive force?

$$I = \frac{2\sqrt{C}}{\sqrt{(4L - R^2 C)}} \quad \frac{1}{\varepsilon^{\frac{RT}{2L}}}$$

In which C is the capacity in farads,

L is the inductance in henrys,

R is the total ohmic resistance,

t is the time of one-quarter cycle of the natural frequency.

$$t = \frac{\pi L \sqrt{C}}{\sqrt{4L - R^2 C}}$$

2. What is the maximum current per volt that can flow in any discharging circuit? The limiting value is more valuable for safe design. If R is assumed zero in the above equation, a short and convenient expression for maximum current is:

$$I \text{ max.} = \sqrt{\frac{C}{L}}\, V$$

3. If the frequency is known by measurement or calculation, the current may be derived from the equation

$$I = \frac{V}{L\,\omega}$$

4. The maximum current may be estimated from calculation utilizing the frequency, quantity of electricity, and logarithmic decrement. As an example of calculation of a testing circuit in the laboratory the following is given:

Three one-gallon leyden jars are connected in parallel, and this set is connected in cascade or series with an equal unit by means of about seven feet of No. 0 wire.

Capacity of each jar is about 144×10^{-11} farads

Capacity of all the jars is about 216×10^{-11} farads.

Inductance is about 24×10^{-7} henrys.

I maximum = 0.03 ampere per volt. At 100 kilovolts, the possible maximum current is 3000 amperes.

The frequency is $n = \frac{I}{T} = \frac{1}{2\ \pi\ \sqrt{L\ C}} = 2.25$ millions.

In regard to accuracy of the calculated value of frequency, an error in either capacity or inductance is reduced by the square root in the result. An error of 25 per cent. in these values gives an error of only 5 per cent. in the frequency.

The resistance which will just destroy the oscillatory discharge of the leyden jar circuit in the foregoing description is 7000 ohms.

Subdivision of Frequency

Natural frequency of lightning should not be confused with the multiple stroke or the frequency of recurrence of strokes. Frequency is distinguished by analysis under four heads.

1. Lightning strokes often come into a station during a storm at an average rate ranging from two per minute to one in five minutes.

2. Each of these flashes, which appears to the eye as a single flash, may often be two or more distinct successive strokes distributed over a second or less. In the next paragraph the analysis of each of these individual strokes into oscillations gives the natural frequency of the discharge.

3. Many of the discharge records of the rotating-film apparatus for measuring duration are in the form of a uniformly broken line whose parts correspond to the half cycles of the discharge current. This frequency, when it existed, was of the order of the natural frequency of the transmission line, about 3000 cycles per second.

4. Each one of these waves may be made up of higher frequencies superimposed upon it. Of these high frequencies the only ones measured were of the order of a millon cycles per second.

Comments and data on the four subdivisions. 1. Frequency of recurrence, or rapidity of lightning discharges. A note of all the discharges during two storms which came into the substation from three circuits and were recorded on the tape lightning recorder is herewith given.

Condensed record of second storm of August 12, 1907. First discharge 1:10:36; last discharge 1:59:4, p.m. Total number of discharges 42. Average number of discharges about one per minute. Maximum number of discharges per minute was three. In the second storm of August 9, 1907, there were 33 strokes in 43 minutes. The rapidity of discharge in these storms was not unusual.

2. *Multiple strokes.* In the second storm of August 12, there were two cases of multiple strokes. In each case there were two strokes within a second recorded on the paper tape. In the second storm of August 9, 1907, there were five cases of multiple strokes. When multiple strokes followed each other more rapidly than 0.2 second, the paper tape would not show a separation. The more rapid multiple strokes are recorded on the duration apparatus, Figs. 3 and 4. Discharge marked *a*, Fig. 4, shows three distinct strokes; discharge marked *b*, shows five; discharge *c*, shows two; discharge *e*, shows seven; discharge *f*, shows three; and discharge *g*, shows one. In this storm multiple strokes seem to have been the rule. Except for the records shown in Figs. 3 and 4, the films show mostly single strokes.

3. *Natural frequency.* In Fig. 4 the broken line of the discharge is made more evident by drawing definite ink lines at the side of the record for each half cycle where the record was sufficiently distinct to be definite. This is done lest the markings be lost in the reproducing processes. The accuracy of measurement is not high, so the frequencies recorded are divided into eight groups as follows: one stroke of no oscillation, Fig. 5; one stroke at 840 cycles per second; eight strokes at about 1400; six strokes at about 2000; two strokes at about 2500; twenty strokes at about 3000; and one stroke at 4000 cycles per second.

A careful inspection of the records brings out irregularities in the time between half cycles of some of the records, especially at the beginning of the discharge. This might be expected from the theory, but the constancy and regularity of the discharge of the line to earth at about 3000 cycles is surprising. A tentative explanation of the phenomena is herewith given: out some distance on the line a storm cloud hovered and induced a charge on the line which leaked over the insulators. The induced charge may have covered a mile or more of the line and may have been located at any point between the middle and end. The cloud discharged and freed the induced charge. The charge immediately tried to spread over the entire line. Apparently there was considerable dissipation of energy in the earth resistance. The first effect, usually, is a static wave of potential which reaches the end of the line where the instrument is placed, jumps the two series gaps of the instrument to the earth, pours out the entire charge to earth, overshoots the zero potential, and leaves the line oppositely charged. The gap sparks again and the potential again overshoots the zero and again the charge of the original sign covers the line. During each oscillation the current passes through the resistance of the earth, line, and spark, which uses up the energy. Finally, after a few half cycles, the potential can no longer jump the gaps to ground and the remaining charge finally settles down evenly distributed over the whole line.

Theoretically, the location of the freed charge on the line

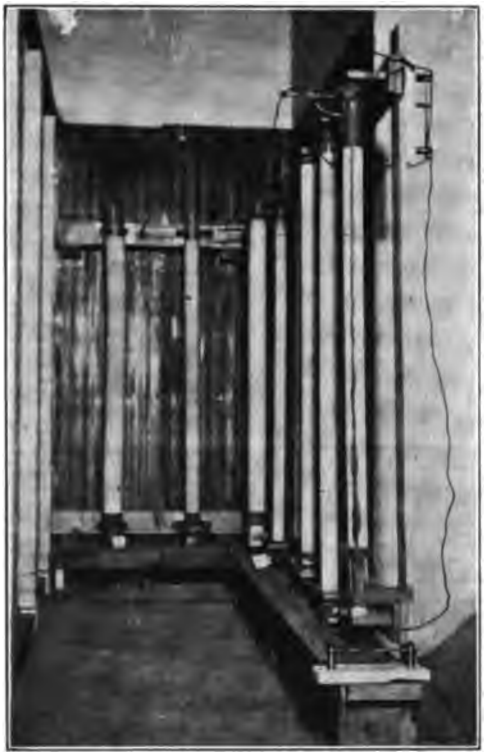


FIG 9.—High frequency recorder as installed in the high-tension gallery of the sub-station

relative to the ends should make a difference in the rate of discharge to ground. Since one end of the line is insulated, the part of the charge which travels to this end should be reflected back to the discharging end after that end has begun to discharge. This should change the regularity of the discharge, more or less, according to the location and length of line covered by the original charge. In confirmation of this theory several records show an irregular spacing and minor peaks of current at the beginning; after a few half cycles, however, the effect of these reflected waves disappears and the line seems to oscillate as a whole. It may be noted here that the number of half waves in the record furnishes a means of estimating the minimum potential that the initial charge might have had.

4. *Very high frequencies.* In Figs. 3 and 4 the discharge was analyzed into waves having a frequency of the order of the period of the line. The next step is to analyze the harmonics in each of the waves. There may be two explanations of the presence of the higher frequency: either the cloud lightning may discharge with a frequency of the order of one million cycles per second, or the traveling wave along the line may meet with inequalities of capacity and induction which cause ripples in the waves. To detect these waves a recording high frequency meter was constructed. The meter as installed in the high-tension gallery of the Silverton sub-station is shown in Fig. 9. It consists of nine vertical coils of wire each closely wound in a single layer on a glass tube. The glass tubes and the wire are of varying sizes so as to give each one a different value of natural frequency.

The fundamental frequency and frequencies of the higher harmonics of each coil are given in the following table.

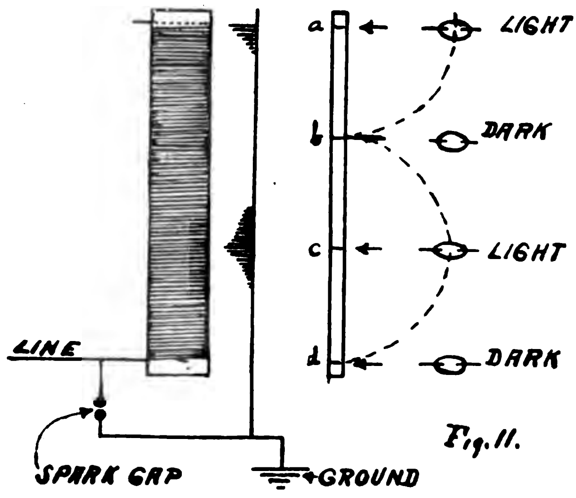
Coil No.	Fundamental frequency	Third	Fifth	Seventh
1	120,000	360,000	600,000	840,000
2	175,000	525,000	875,000	1,225,000
3	232,000	696,000	1,160,000	1,624,000
4	290,000	870,000	1,450,000	2,030,000
5	364,000	1,092,000	1,820,000	2,548,000
6	593,000	1,779,000	2,965,000	4,151,000
7	721,000	2,163,000	3,005,000	
8	890,000	2,670,000		
9	1,130,000	3,390,000		

Some of these values overlap and give a check on the results; for example, the third harmonic of tube No. 5 almost coincides with the fifth harmonic of tube No. 3.

The high-frequency instrument utilizes the principle of the stationary wave. One coil of the meter is represented diagrammatically in Fig. 10.

Parallel to the tube is an antenna toward which the brush discharge takes place. The tube is represented as receiving an oscillation which is three times its natural frequency of vibration. This is indicated by the two patches of brush discharge.

Fig. 11 shows the distribution of potential along the tube. An electrical wave passes up the tube to the dead end *a*, is reflected back, and meets the adjacent incoming wave moving in the opposite direction. When the waves cross each other at *b*, they have opposite potentials and neutralize each other. When the first reflected wave arrives at *c*, it crosses the peak of the



FIGS. 10 and 11.—Diagrammatic sketches showing the principle of operation of a high-frequency recording unit

next wave when both waves have the same sign of potential. The result is double the potential of one wave. Since, if the tube is in tune, all incoming and reflected waves cross each other at the same point, stationary waves are produced on the tube. The presence of these stationary waves can be shown by holding a small vacuum tube near the coil, Fig. 11. This much has been used by wireless telegraph engineers in conjunction with a capacity which can be varied to resonate the tube to the oft-repeated waves from a wireless sender. No such adjustment can be made in studying lightning, as the discharge comes in without warning, is usually over in one thousandth of a second, and does not repeat itself. An automatic recording device was found in employing a long photographic film in the static field between the tube and antenna, Fig. 10. The location of the film had much to do with the success of the results.

The conditions of the operation of the instrument may be explained by their analogy to musical resonance.

a. If a piano is pedaled to free the strings from their individual dampers, and a note is sounded on a cornet at some distance, the string on the piano corresponding to the tone of the cornet will be set in vibration and can be heard after the cornet note is stopped.

b. If the pitch on the two instruments is not quite identical, the string will respond with less vibration. If the pitch of the cornet falls midway between two adjacent wires both wires can be made to respond to a slight extent.

c. If the cornet is blown loudly near the piano the violence of the vibration will set in movement nearly all of the wires.

Corresponding to the conditions of the musical analogy, the high frequency instrument cannot, without precaution, be used to measure the harmonics of a lower frequency, say 3000 cycles, unless these harmonics greatly predominate over the fundamental. In consequence, the high frequency of the usual discharge coming from a distance out on the line as shown by most of the records of the duration apparatus did not give a record. The fundamental charge of low frequency travels along the coil, and its potential is so much greater than the potential of the higher frequency that it blackens the film over its entire length. If, however, a cloud just over the instrument is discharging at a high frequency, this high frequency potential will be forced onto the line and may affect the instrument.

If the difference of potential of the fundamental wave is limited to a small value by using a spark gap, the harmonics become relatively more effective. Due to the unpropitious conditions on the line, adjustments, and lack of facilities, only two of the records were of value.*

The high frequency recorder is better adapted to the study of cloud lightning directly. The receiving antenna can be made with a large coefficient of damping so that sensibly nothing but the forced oscillations will affect the film, and furthermore, local sparks can be eliminated.

* The entire credit for the measurements obtained are due Mr. Peek for his painstaking and tireless efforts.

Quantity of electricity. Fuses have been used to indicate the relative severity of a lightning stroke, but a fuse in itself gives no absolute information regarding the quantity of electricity in a lightning stroke. The factor of duration enters, and this depends on the damping effects of resistance, various losses during the discharge, and the initial lightning potential. A small quantity of electricity oscillating for a long time may blow a fuse, while a hundred times as much discharging through a damped circuit might leave it intact.

The essential features of the apparatus for measuring quantity are a fuse that just blows and a duration apparatus that records the number of oscillations through the fuse. If the refinement of taking the logarithmic decrement into account is neglected for the moment, the equation for quantity is simple.

Let Q be the total quantity passing through the fuse (some multiple of the quantity freed on the line),
I the average effective current,
t the total duration of the stroke,
n the number of half-cycles of discharge,
J the joules of energy to raise one centimeter of the fuse to its melting temperature,
R the resistance of the fuse per centimeter length,
$T\phi$ the rise of temperature, centigrade, to melt the fuse,
w the weight of the fuse per centimeter length in grams,
S the mean specific heat of the fuse metal.

Then

$$J = I^2 R t = \frac{Q^2 R}{t}, \quad Q = \sqrt{\frac{J t}{R}}$$

In which $J = T \times w \times S \times 2.4$, and lightning $(q) = \dfrac{Q}{n}$

Nothing but approximations are necessary in these calculations, therefore the heat radiated from the fuse during the brief period of the discharge is neglected or rather allowed for by choosing, for calculation, the size of fuse one above the fuse melted out. The larger the fuse that is blown the less the relative value of radiation, because the surface relative to the volume is also less. Our interest in the quantity of electricity in the lightning stroke increases as the quantity becomes greater, and fortunately, for the upper value, the accuracy correspondingly increases. Other things being constant, it requires a fuse of four times the weight to hold a charge of twice the quantity.

There may be a fraction of the original quantity left on the line after the discharge has passed due either to a gap in the circuit or to the gap of the fuse that blows. This residual quantity has nothing to do directly with the result because there has been already more than one oscillation. Its indirect bearing is beneficial if approximate calculations are being made. The fewer the oscillations recorded the nearer is the average quantity to the original maximum quantity set free on the line.

The arrangement of the apparatus for measuring the quantity of electricity is shown in Fig. 12. A duration recorder is shown

FIG. 12.

DURATION, FREQUENCY, AND QUANTITY.

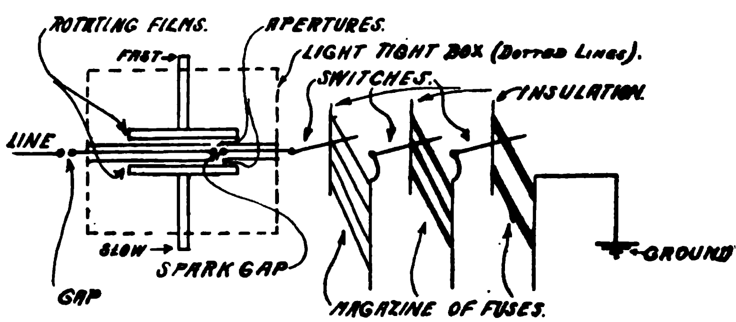


FIG. 12.—Combined apparatus for measuring duration, frequency, and quantity of electricity

in series with three magazines of fuses. Each magazine of fuses consists of a set of parallel fuse wires placed one above the other. At one end they are connected to a vertical post of some insulating material and at the other to a metallic post. In front of this fence of fuse wires is a vertical post carrying a hinged arm which rests on the top wire. As each fuse blows the arm drops automatically on the next fuse below. All the fuses in one magazine are the same size but the fuses are graded in size in the separate magazines. In operation the arc will hold in the vapor of the small fuse while a larger one melts. For this reason a metal of good arcing quality, like lead for example, is preferable.

Another method of making the calculations for quantity of electricity is by calibration of the fuses using an oscillograph to measure current and time. Using a voltage too low to maintain an arc, currents of increasing values with the same size fuse are used and a curve made between the factors of current and time. For very short intervals of time the equation seems to show independence of the radiation and is:

$$I^2 R t = \text{constant}, \qquad \text{or } I^2 t = k$$

Using the data taken from one of the tests, which was a heavier stroke than the average but not so severe as some others, a value of 0.032 coulombs was found for the total quantity that passed. It happened that multiple strokes occurred each time a fuse test was made, so a near approximation of the quantity of lightning induced by the cloud cannot be made on account of the radiation during the interval of the multiple strokes. A rough approximation of the quantity in this case is 0.003 coulombs. If this quantity of electricity was spread over a mile of line having a capacity between line and ground of 0.01 microfarads, the initially impressed voltage would be about 600,000 volts. The question whether a voltage of this nature will jump an insulator or not, is not solved by impressing a constant voltage of the same value on the insulator to determine if it will spark over, but it is entirely a matter of the relation of the dielectric-spark-lag of the insulator to the time constant of the line wire. The inductance of the line opposes momentarily the spreading of the charge over the entire line. A wooden cross-arm gives a much greater dielectric-spark-lag than an iron cross-arm. This subject is treated experimentally later under its appropriate head.

A refinement in the calculation of quantity requires the integration of the instantaneous value of current over the duration of the discharge.

$$Q = \int i \, d t$$

in which i may have the approximate form

$$i = k_1 \, \varepsilon^{-\frac{Rt}{2L}} \sin k_2 t.$$

Quantity meter of ballistic principle. Instead of using fuses, which are destroyed and have to be replaced, an ordinary hot-wire ammeter may be used if it is properly calibrated and the hot wire sufficiently insulated so that the drop of potential due both to $I R$ and $L \omega$ do not cause a short circuit. In the laboratory this method is convenient but in the study of cloud lightning effects the hot-wire ammeter has the disadvantage of leaving no record and therefore requires constant watching and patient waiting.

If quantity and frequency are known, this method can be used to measure duration or number of cycles.

Movement of charges on parallel wires. It is seen from the low frequency of the discharges of Figs. 3 and 4 that the concentrated charge under a cloud flattens out over the line when set free. The free movement of the wave seems to be greatly retarded by the surface resistance of the earth directly under the line wire. Incidentally it may be noted that a short line will be harder hit than a long one by the same cloud conditions, although, by the law of chance, not so often.

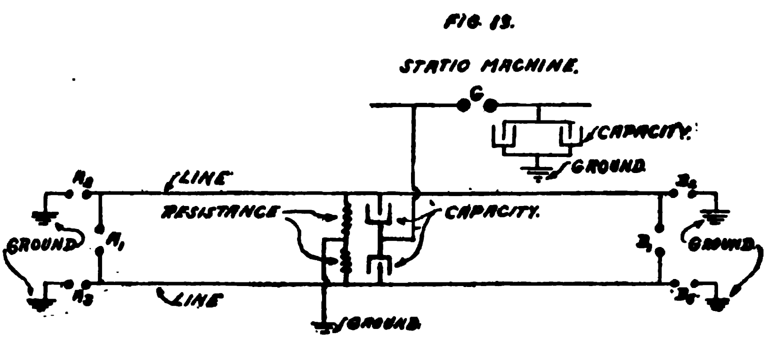


FIG. 13.—Laboratory test illustrating the mutual induction between two moving lightning charges

There is another phenomenon observed which modifies somewhat the potential of the traveling wave. This was first observed on a two wire circuit. When equal induced lightning charges on the two parallel wires are freed, electro-magnetic induction will oppose the flow in the same direction. With a fixed length of gap at each end in each wire of a two wire circuit, only one gap would spark unless the discharge was either unusually heavy or quite near the station. This same phenomenon was checked up in the laboratory on a circuit represented in Fig. 13.

The first test utilized the gaps A_1 and B_1 only. When properly adjusted, both of these gaps sparked simultaneously. The second test utilized the gaps A_2, A_3, B_2 and B_3. Under certain conditions of test the wires would spark to earth invariably at opposite ends. These tests seem conclusive of the tendency of the mutual inductance to force the equal charges in the opposite direction along the circuit. Line to line discharges due to cloud lightning sometimes take place. The above phenomenon no doubt is partially the cause of such discharges.

A brief description of the two lines on which observations were made follows.

The Pueblo and Suburban Light and Power Co. The Pueblo and Suburban Light and Power Co. has 24,000-volt lines between Pueblo and Victor (altitude 10,000 ft.), Colorado. The power house is at Skaguay, somewhat lower than the Victor substation. General observations only were made here. The measuring instruments did not arrive until the beginning of August and work was then taken up on the Animas Power and Water Co's. lines as the storms were more frequent in that locality in the late summer. All the new measurements were made on the line during the latter part of August, 1907.

The Animas Power & Water Co. The Animas Power & Water Co. transmits energy from the power house (8,000 ft. altitude) to the sub-station (9,500 ft.) at 43,500 volts, with the neutral grounded at the power house. There are two separate lines, one at the bottom of the cañon to minimize the electrical disturbances in summer, and the other carried directly up 1000 ft. to an elevated plateau to minimize the trouble due to snow slides in the winter.

At the main substation, the voltage step downs to 17,000 volts delta. On the 17,000-volt system there is one customer's station (100 kw. capacity) with grounded neutral; but this seems to have no beneficial effect when recurring surges play over the system.

On the system are about 30 customer's stations, all mines or mills except the city circuit of Silverton. The lines run along the cañons, up the gulches to the mines, and over the ridges. In two places the lines reach an altitude of over 13,200 ft. The difference in altitude is about 4000 ft. on the 17,000-volt system, and 5200 ft. on the entire system. The system covers a lightning area estimated at 270 square miles. The 17,000-volt circuit is not in duplicate. The feeders have sectionalizing switches at several points. At the mines, the potential is transformed to 440 volts and, in several places, is carried overhead for several hundred yards to different tunnels.

The severity and frequency of lightning storms during the season has been previously noted. Two storms often occur in one day. Storms sometimes hover over some part of the system for 24 hours. In that neighborhood it seems that the cool winds from the north meet the warm winds from the stretches of desert to the south. It is probable that the problem of lightning protection here is as difficult as any place in the world.

Some of the methods and instruments for measuring lightning potential, frequency, duration and quantity have already been described. A most valuable aid was a lightning recorder—a development of the tell-tale paper.

Lightning recorder. One of the types of lightning recorder used consisted of a cylinder, uniformly rotated by geared power,

FIG. 14.

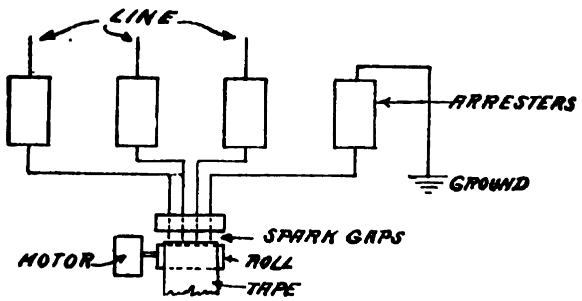


FIG. 14.—Lightning recorder to show the discharges through a lightning-arrester

carrying a ribbon of paper, Fig. 14. Four electrodes pointing toward the axis of this cylinder and separated from the circumference by clearance only, were connected to the lightning-arrester. This recorder was placed at the neutral or multiplex connection of the arrester having one electrode connected to each phase and one to the ground. This arrangement differentiates between line to line, and line to ground discharges. A single-phase induction motor was used for power in the first set of instruments. This power was carried through multiple gears which permitted of four speeds in multiples of tens. Most of the records were taken with a speed of about 0.1 in. per second. Later designs of recorders using clock work have the advantage of greater uniformity of speed and independence of the voltage and frequency of the circuit.

The records show the exact time and phase of the discharge, and, by the size of the punctured hole, give an indication of the relative quantity of electricity discharged. If, however, the arrester is connected to a circuit supplied with power, the dynamic current will burn away all trace of the original hole produced by the static discharge. When a phase is accidentally grounded, the record tape shows which phase is producing the surges and how long the trouble lasts.

Lightning discharge records. Some typical and unusual records of lightning discharges from lines are herewith reproduced. Fig. 16 is the record of an aluminum arrester taking a recurrent surge due to an arcing ground to the third phase. After 2 seconds of heavy discharge the trouble nearly cleared itself but it was 25 seconds before the surges were entirely over.

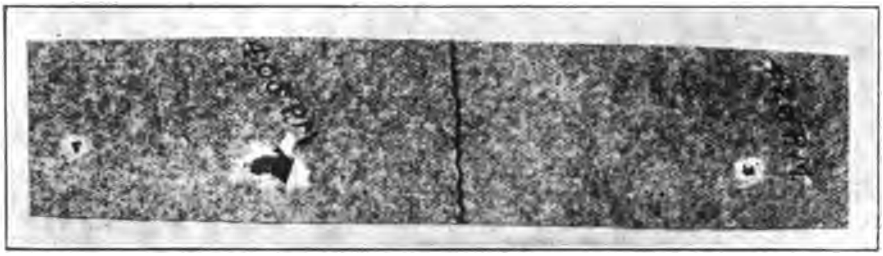


FIG. 15.—Three discharges of lightning through a cone-type aluminum arrester on an idle line. The central hole is the largest recorded, due entirely to static, during the season. The discharge caused a loud report

Fig. 17 shows three simultaneous records; to the left is a record of 4 multiple strokes on the telephone circuit, in the middle the discharge of an aluminum arrester, and to the right the discharge of a liquid-electrode arrester. The telephone record shows tiny holes encircled by ink rings. This is a static hole of usual size on the telephone circuit when the storm is over five miles distant. The aluminum arrester record shows a somewhat larger hole which was enlarged by the dynamic current. The liquid-electrode arrester record shows large holes burned by the dynamic current and shows furthermore that the four discharges were so close together that the holes burned into one. Phase three, with the same single gap setting, did not spark. The aluminum arrester was inside the choke-coils and only one of the four discharges passed through the choke-coil. It should be

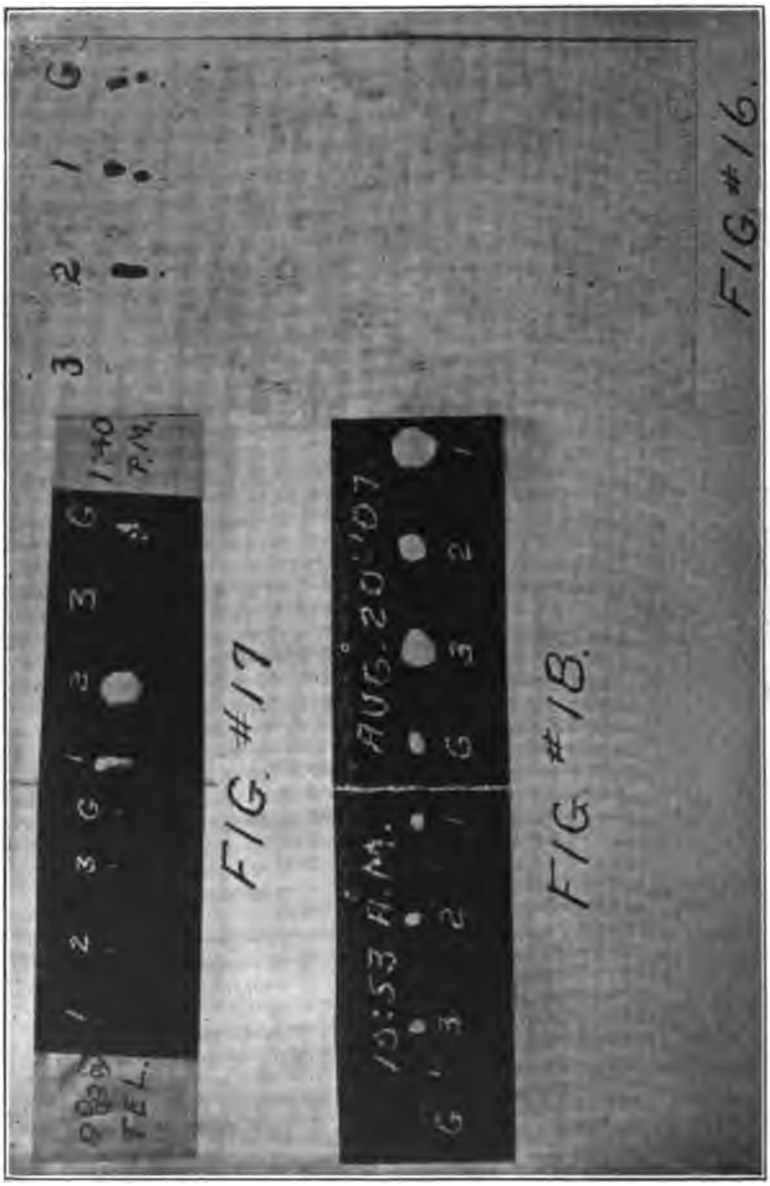


FIG. 16.—Discharge of continuous lightning through an aluminum arrester. There was an arcing ground in phase 3. Phase 3, shows an initial discharge only. Phases 2 and 1 discharged heavily to ground during 3 seconds, then the ground began to clear itself. The total time of discharge was 40 sec. The records of longer discharges cannot conveniently be reproduced here

FIG. 17.—Three simultaneous records. To the left, the telephone arrester shows multiple strokes; in the middle, the aluminum arrester shows a single discharge; and to the right, the record of the multiple discharges of phases 1 and 2 to ground through the liquid-electrode arrester.

FIG. 18.—Two simultaneous records of discharges through liquid-electrode arresters

noted that these four distinct discharges gave the effect on the arrester of a continuous discharge about one second long.

Fig. 18 shows two discharges of the liquid-electrode arrester. These discharges were normal. These arresters were on different feeders and discharged simultaneously.

Fig. 15. This record is most unusual and remarkable. This tell-tale paper was in the gap between a cone-aluminum arrester and ground on a 24,000-volt line without dynamic potential. The static discharge usually makes a very small hole. The static discharge which punctured the middle hole made a loud report. This was the heaviest discharge recorded during the season. It produced no effect on the aluminum arrester.

Lightning alarms. Since the aluminum arrester is designed to operate continuously for a half hour or more, an alarm may be attached to all these arresters, so that an operator in his office may know when the arrester discharges. He can begin to take precautions to clear the line if the trouble is continuous.

As a convenience in the Colorado tests, Mr. Peek arranged a lightning alarm on the principle of a wireless telegraph receiver which would ring a bell for cloud lightning, or grounded phase, when such occurred on any part of the system.

Equipment for study in the main sub-station of the Animas Co.

1 High frequency recorder on 43,500-volt dead line.

1 Duration meter and low frequency meter on 43,500-volt dead line.

3 Lightning discharge recorders on three telephone circuits.

2 Lightning discharge recorders on 17,000-volt liquid electrode arresters, outside of choke-coil.

1 Lightning discharge recorder on 17,000-volt aluminum cell arrester, on bus-bars.

1 Lightning potential recorder on 17,000-volt line.

1 Lightning alarm (general).

1 Quantity recorder on three telephone circuits.

1 Quantity recorder on 43,500-volt dead line.

To show if discharges were not taken by lightning-arresters, the following device was used:

In the customer's stations, all points of the line which had less insulation than the main line—for example, leads from oil switches and transformer bushings—were wrapped with white paper tape or covered with sheets of paper. Only a few of the customer's stations had lightning-arresters installed. It was vital to locate the trouble. There was no indication in the main station, except the action of the circuit breakers from the resulting short-circuits. Subsequently, the short-circuits could be located by means of the arc marks on the tell-tale papers. Cloud lightning caused several short circuits during the season but in no case did such trouble, due to cloud lightning, occur at stations protected by arresters. Although the two customer's stations giving the most trouble were only two and three miles from the sub-station, a gap of 0.4 in. between line and ground at the main sub-station would not spark over although the spark would jump 3.5 in. and more at the customer's sub-station. This is direct proof that the peak value of lightning potential is much higher at the point on the line nearest the cloud than elsewhere, and rapidly diminishes as the charge travels along the line, dragging its complementary opposite charge along the high resistance of the surface of the earth.

Notes on choke-coils. Twice during the tests the lightning choke-coils showed very materially their beneficial effect. On the line side of the choke-coils an arrester with a single gap length of about 1 in. was installed and another arrester with a gap length of about 0.5 in. on the station side, on the bus-bars. Two discharges occurred over the 1 in. gap which did not discharge over the 0.5 in. gap in spite of its lower sparking potential. The conclusion from the experience is that the discharge must have been of both high frequency and high potential and furthermore that the arrester discharged the lightning before the charge could pass through the standard lightning choke-coil.

That many discharges passed through the choke-coils to the 0.5 in. gap may be due to the conditions of lightning potential and frequency. If a lightning potential in the neighborhood of 1 in. gap equivalent and of moderately high frequency came into the station the choke-coil would allow the potential of the bus-bars to build up to a potential equivalent to 0.5 in. and then start the discharge over the arrester connected to the bus-bars. The aim in the design of choke-coils is to make them just large enough so that if the frequency of the discharge is not sufficient to pile up the potential in front of the choke-coil it is not high enough to injure the end turns of the transformer.

Once during the season a phenomenon occurred which seems to bear out further the experience of the laboratory that a choke-coil may, under certain circumstances, cause a longer spark after the discharge passes through it than it will on the line side.

The laboratory tests were described by the writer in the discussion at Niagara Falls last year. The equivalent effect occurred on the line. From the main sub-station two lines ran south and one north. Each carried a telephone circuit. The lightning recorder on the southern telephone circuits recorded a lightning stroke to the south but the lightning-arrester on the north power line discharged, although its single gap was approximately the same as the arrester on the south power line. In other words, the lightning seems to have passed through a choke-coil to the bus-bars and back through another choke-coil to the north arrester. The hole in the paper punctured by the static on the telephone lines indicated a discharge of medium quantity only. This experience carries only its face value and is not sufficient to be the basis of definite conclusion. A method will be outlined later for studying the operation of choke-coils on transmission lines, looking toward the procuring of definite data.

Experiences with a grounded phase. Several times during the season a phase was accidentally grounded. Each time there was an arc to ground and vicious surges occurred on the lines. Some of these were extremely odd. A lightning stroke came into the main sub-station on the 43,500-volt line. The lightning-arresters were designed with permanent resistance in series limiting the current to about 6 amperes at double normal potential; consequently the discharge took place between a phase wire in the station and an iron girder, some 18 in. distant. This arc roared continuously during the entire trouble. The liquid-electrode arresters on the 17,000-volt circuit discharged continuously for several minutes but were finally disconnected by their fuses as they had reached their limit of endurance. A switch broke down at Camp Bird Mill, throwing a ground and short-circuit on the 17,000-volt circuit. An arc jumped from each of two phases downward and out about 16 in. to insulator caps and across between caps 20 in. making a total of 52 in. Subsequently the arc rose on each side to the ceiling girders making a total of 6 ft. Meanwhile all the iron pipes and rods in the building were alive with brush discharge. The static from the iron pipe, carrying the 110-volt lighting wires, discharged against the white brick wall so viciously as to leave a permanent dark streak. The 110-volt light cables were short-circuited by induced sparks from the arcs on the high tension circuits. A spark jumped several inches from a pipe to the iron rod actuating a 2300-volt oil switch. The trouble was removed by opening the switches at the power house. Except the oil switch at Camp Bird no apparatus was damaged.

This trouble arose from the lack of a good lightning-arrester for transitory lightning. The secondary trouble was due to the lack of an arrester that had a long endurance for continuous surges. The cone-type aluminum arrester was not installed until later. To any witness of these phenomena there can be no doubt that the discharging of these continual surges is the most difficult problem in lightning protection.

Another arcing ground. The Champion mine had no protective apparatus installed. A stroke of lightning came in and damaged a 17,000-volt transformer bushing. Subsequently this transformer was thrown back into service on the 17,000-volt circuit for a minute. It arced over its bushing to its case. The case was insulated from the earth by wooden supports. The lightning-arresters in the main station did not discharge. Later the switch was closed for a little longer period with the same result. A third time the switch was closed, the case began to arc to ground and the lightning-arresters began to discharge continuously at the substation until the transformer was again disconnected.

Subsequent arcing grounds. Later in the season a cone-type aluminum arrester was installed on the bus-bars of the 17,000-volt system. A grounded phase occurred twice after this arrester was installed. The arrester discharged continuously for over 15 minutes, and relieved the line, until the ground was removed.

Direct stroke. The writer had planned to make a direct study of cloud lightning but, due to the time absorbed by the measurements on the line and an accident, Fig. 6, it had to be postponed. Indirect studies were made both on the line and in the laboratory. There are no overhead grounded wires on the Animas system. So far as practicable the lines are run along the bottoms of the cañons and gulches. The mountain sides are steep and give some protection, no doubt, against induced static. At many points the lines run exposed up the sides and over the ranges but by the law of chance all these points were uninjured, so far as known, except one. This happened on the 43,500-volt line about a mile away from the power house. At the power house, this line rises abruptly 1000 feet and is carried along a high plateau. At the point struck, five poles were more or less splintered, although none was rendered unserviceable, and incidentally, no apparatus was lost in the power house. Splinters were thrown edgewise out of the surface of the poles to a distance of thirty feet. The hole or groove was often less than ¼ in. wide but 1 in. or more deep. Along the line, quite near, with their tops higher than the wires, were several trees. The question arises, why should the lightning choose a path through the high insulation of the poles rather than strike the tall sappy trees of greater conductivity? The reason for this differentiation may possibly be due to chance but it seems to lie in the conductivity of the horizontal line relative to that of the earth and tree. As further evidence of this, two direct strokes occurred in this neighborhood a year before which scarred the poles and there was no tree damaged near the line.

It may be imagined that when a charge on a cloud begins to concentrate in a discharge path, the corresponding induced charge on the earth concentrates under the same point.

The potential at the tree top depends directly on how much static electricity can get to it through the relatively high resistance of the tree and earth. Although the line is not connected to the ground, it holds a considerable charge due to gradual leakage as the cloud moves over the line. This charge can concentrate with no impedance but the inductance of the line, and due to this concentration the excessive displacement current on the line may swing the cloud discharge into this path. Once the lightning strikes the line, the potential builds up too rapidly to be released by spreading the charge over the line and consequently it takes the shortest single path or multiple paths down the poles. The laboratory tests bearing on this theory are given below.

Many of the strokes of cloud lightning observed were between clouds and not to earth.

Wooden versus metal cross-arms. Under the heading of lightning potential the question was raised " does series resistance affect the spark potential of a needle-gap?" The answer was, that it affected it only slightly if the resistance was not carried too high. With a discharge current of half an ampere, there is no great change in the spark potential even for suddenly applied potentials of high frequency. When, however, the resistance in series with a gap is greatly increased, the current necessary to charge the static of the needle points and furnish the energy for the brush discharge which precedes a spark, is retarded and an equal gap in parallel having no series resistance will take the spark.

The same phenomenon occurs on transmission lines in differentiating between wooden cross-arms and metal cross-arms. If the wood is dry there is no question but that the insulation between the two line wires is greatly increased. On the other hand, if the wood is wet and dusty the value of the wooden cross-arm is not so evident. The following experiments were made to show that on low frequency, say 60 cycles, the wet wood gives no better insulation than the metal, but at high frequencies it gives much better insulation. A wooden cross-arm was arranged as shown in Fig. 19: two porcelain tubes held wires 1.7 in. above

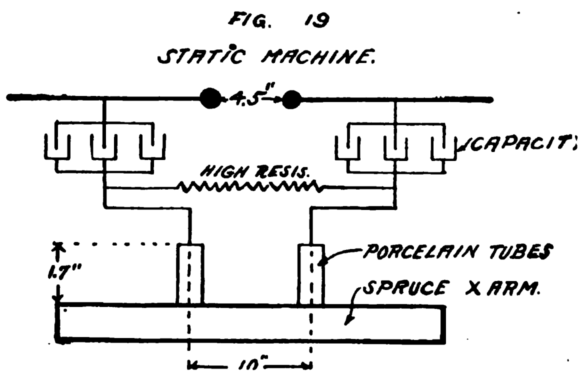


FIG. 19.—Diagram of connection for the laboratory test proving that the wooden cross-arm has great advantages over the iron cross-arm in resisting lightning strokes

the surface of the wood and 10 in. apart. On the upper surface of the wood tin foil or a wet towel was placed in imitation of line conditions. Fig. 19 shows the conditions of the second test. The first test was made on a 60-cycle circuit with a needle-gap in parallel with the cross-arm. The voltage breakdown was the same whether the wet cloth or the metal was used. By transformation, the voltage was 46,900 (eight readings) and by needle gap it was 3.5 in. (52,000 volts by interpolation from the curve). This higher indicated potential by the latter was due to local oscillations set up by corona discharges over the porcelain top. After the cloth had dried out somewhat the spark potential by transformation rose about 2 per cent.

The potential was then suddenly applied by means of the apparatus shown in Fig. 19. The frequency was 2.25 million cycles per second. The applied potential was a 4.5 in. gap between spheres 1.25 in. in diameter. The equivalent needle gap was 5.6 in. (68,000 volts) when the cloth was used very wet. The equivalent needle gap was only 2.5 in. (42,000 volts) when the metal plate was used between the porcelains. This disruptive voltage is even less than with the gradually applied potential. It results from the multigap effect of the metal plate. The plate has a static capacity which takes an appreciable charging current across the gaps. It is well to note that 5.6 in. was the limiting potential that the needle would spark over, so the actual conditions would have been even more favorable to the wet wood if the applied potential had been greater. Taking it as it was, the wet wooden cross-arm was 160 per cent. better than the metal as a protector against high frequency lightning and the metal cross-arm is only 80 to 90 per cent. as good for lightning as it is for generator potential.

Although these figures will, no doubt, be somewhat modified by changing the relative conditions of the test, it is safe to conclude that a wooden cross-arm is always to be recommended from the standpoint of insulation and would be a most desirable and economical feature even on iron towers. It is usually cheaper to add insulation with wooden cross-arms than it is to obtain it with added porcelain in the insulator. When the wooden cross-arms is only damp or dry it may add greatly to the insulation against lightning. These tests have a bearing on the use of insulator horn-gap protectors that will be apparent to the engineer.

General Comments on the Arrester Equipment of the Animas Company

Last summer the equipment of arresters consisted of four 43,500-volt special multigap arresters using concentrated series resistance, four 17,000-volt multigap arresters using distributed series resistance, and five liquid-electrode arresters. Two of the 17,000-volt arresters were rendered inoperative by having two liquid-electrode arresters installed in parallel. The liquid electrodes invariably took the heavy discharges. The following brief comments are made on the operation of the arresters during the season:

The series resistance in the high-tension arrester was of such value as to limit the dynamic current flow to six amperes at double normal voltage. The lightning strokes in this district were much too severe to be discharged at this limiting discharge rate, consequently three times during the season discharges took place between the station wiring and the girders, jumping 18 in. or more to ground. The 17,000-volt arresters with the series resistance limited the current discharge to 12 amperes, and usually were able to take the discharges. In one noteworthy exception, an arc took place between a lead-in wire and the ground. The liquid-electrode arrester on the 17,000-volt circuit gave satisfactory operation in all cases of transitory lightning, but during grounded-phase conditions the arrester continued to operate for some minutes until it was somewhat damaged. These arresters are not designed satisfactorily to take care of continual lightning, although they have an endurance that is several hundred or thousand times the endurance of the multigap arrester. If the entire system had had adequate protection against transitory lightning there would have been no trouble with recurrent surges, with but one exception—a direct stroke on the high-tension line. Since there are more than thirty points to be protected on the 17,000-volt system and only seven points protected, recurrent surges from failure of insulation at the unprotected stations occurred several times during the season and interruptions were caused by short-circuits as the result of sparks at unprotected stations. Additional arresters for the system were on order but arrived too late to be installed for the season of 1907.

The full protection of the system involves: first, the installation of one liquid-electrode arrester at the power house on 43,500 volts; secondly, one gap-aluminum arrester at the sub-station on the bus-bars, 43,500 volts; thirdly, three additional liquid-electrode arresters on the 17,000-volt circuit; fourthly, ten additional aluminum arresters on the 17,000-volt circuit; and, fifthly, completion by installation of reconstructed multigap arrester. The units of the multigap arrester formerly on the 43,500-volt circuits were utilized in the special design of arresters for the 17,000-volt circuit. By this change practically no money was lost in the lightning-arrester investment.

Location of arresters. The object to be obtained in the location of arresters to the best advantage is as follows:

Aluminum arresters should be distributed as uniformly as possible over the system, choosing the more important stations where there is an actual attendant, or one in the near neighborhood. These arresters should have their series gaps set at a comparatively low value in order to take care of recurrent surges from an accidentally grounded phase. The liquid electrode and multigap arresters at adjacent stations will require a higher abnormal potential to start the discharge and by proper proportioning should be protected against recurrent surges by the adjacent aluminum arresters. Recurrent surges have, in general, lower frequency than lightning from induced clouds and are not so much localized. Therefore the lightning-arrester designed for transitory lightning should discharge any induced cloud effects in its locality, but should pass on recurrent surges to the nearest aluminum arrester. In stations where there is no attendant, and none available within five minutes' call, the setting of the gap of the aluminum arrester should be such as to make its action transitory, except for exceedingly bad local conditions. In the main sub-station the aluminum arrester should have a gap setting only slightly above line potential with the object of making these arresters discharge, as far as possible, continuous lightning from outside points on the line. The object of this is twofold; first, to keep the line potential down; secondly, to draw the attention of the attendant to the fact that there is trouble on the line which must be located and corrected.

Since the aluminum arrester is designed to have a duration of discharge of a half-hour or more, this should give sufficient time to locate the particular circuit on which the trouble occurs and make the necessary switching without disturbing the rest of the system. It is evidently inadvisable to have any unattended aluminum arrester discharging surges which do not make themselves known to the station attendant, because the result would be final disconnection of the aluminum arrester from the circuit by the blowing of its series fuse, thus leaving the station without any protection whatsoever. After such an arrester is disconnected the surges will be carried on to the next arrester or into the sub-station. In localities where there are two or more stations near each other an endeavor should always be made to utilize a multigap arrester at one, and either an aluminum or liquid-electrode at the other. In this way even the multigap arrester of low discharge rate could be utilized, since the adjacent arrester of large discharge rate would assist in discharging the cloud lightning.

Characteristics of the gap-aluminum arrester (concentric cone type). First. The general characteristics of the aluminum cell with a definite limiting voltage, above which the current flows through freely, are known. At voltages above the critical value the film has no resistance and the only resistance in the circuit is the internal resistance of the electrolyte. In consequence of this characteristic the discharge rate at double normal voltage can be made as high as desirable.

Secondly. When the aluminum plate with its film-coated surface stands in the electrolyte, the film dissolves more or less rapidly according to the nature of the electrolyte. This dissolution can be made very small or considerable by the choice of the electrolyte.

The *third* feature in regard to the arrester is its endurance to continual lightning. The chief obstacle to the length of endurance is the same as in all other electrical apparatus; namely, heating; the arrester can be made to endure from a minute up to six months or longer by appropriate designs.

The *fourth* factor in the design of the arrester is its total life. The arrester should be given a life of several years. This is influenced by the nature of the electrolyte as well as the number of times and duration of the discharge.

The *fifth* factor entering into the design of the arrester is the cost. The four other factors can be made as nearly perfect as desired, but with the limiting value of cost the three first named factors are somewhat at variance with each other; for example, with the same arrester it is possible to give high current discharge rate and low dissolution of film, but in so doing the duration of the discharge will be diminished. On the other hand, the duration of discharge and the low value of dissolution of the film may be maintained, but the high rate of discharge sacrificed somewhat. In designing arresters the aim has been, in general, to meet the specific conditions imposed by recurrent surges on a system.

Until the development of the aluminum arrester there was no arrester which would take care of recurrent surges. This condition was one of the justifications for the use of a grounded neutral system. To meet the condition of recurrent surges requires a lightning-arrester that will discharge these surges for a time long enough for switching to be carried out to isolate the circuit on which the trouble takes place; meantime a repair man can be well on the way to the point where the damage has been done. A half-hour or an hour would usually be sufficient to do this. Therefore in the general design of the arrester to take care of recurrent surges the parts should be so proportioned as to give, first of all, the duration of discharge; secondly, the parts should be so proportioned as to give a discharge rate high enough to take care of any kind of induced or internal lightning. The value of this discharge rate is 1000 amperes at double voltage, correspondingly higher at triple voltage, and discharges all the way from 125 per cent. abnormal voltage, where the spark takes place, up to the highest voltage reached. In order to get this favorable condition, an electrolyte is chosen which is not the most favorable from the standpoint of dissolution of film; consequently in this arrester it becomes advisable to connect it occasionally to the circuit. In this matter there is a wide latitude of time; for example, it may be daily, or weekly, or even longer under the usual conditions of temperature. It has been found advisable, not only from the standpoint of the condition of the arrester, but also from the standpoint of the education of the operators, to recommend that these arresters be connected to the circuit at least once a day. To the writer's knowledge circuits have been shut down because the operator became frightened at the continuous discharge of the lightning-arrester when trouble occurred on the circuit. When continuous lightning occurs on the circuit it is desirable to have as long a duration of discharge of the arrester as possible. If the arrester has not been connected to the circuit for some time there is an initial rush of current which, although doing no harm to the arrester, warms it up unnecessarily and thereby shortens the possible time which the arrester would have operated had the film been in prime condition at the start. The wear due to this daily testing of the arrester is inappreciable and the time of the attendant is valuably spent.

When the aluminum arrester is to be used as a line arrester or in isolated stations where it is desired to take care of transitory lightning only it is necessary to make but two changes; first, a change in electrolyte to give less dissolution of film; secondly, as stated previously, the length of horn gap in series should be set at a value that will not be affected by the numerous surges of harmless abnormal potential which occur on transmission systems. Since the ordinary lightning-arrester does not begin to operate until at least double voltage is reached, and since practically all apparatus is tested at double voltage, it should be recommended that the gap of the line arrester be placed at not less than double voltage. It should be noted that if the arrester gives an initial current rush after being off the circuit for a long time, no harm will be done unless such initial rush of current should throw the circuit-breaker at the station. The slight amount of heating that occurs from this initial rush, lasting for not more than a very few cycles, and usually not more than one cycle, is negligible in the aluminum arrester used as a transitory lightning-arrester. This arrester may be allowed to stand for long intervals without connection to the line.

By sacrificing the duration of discharge, the arrester can be given a discharge rate of 2000 amperes at double normal voltage, simply by an increase in the amount of the electrolyte in the same set of aluminum cones.

To facilitate the testing of the aluminum arrester, the horn gaps are made in special form to act in three capacities: first, as a horn gap; secondly, as a short-circuiting switch to the gap, and thirdly, as a disconnecting switch.

Some Auxiliaries to the Gap-Aluminum Arrester

The lightning alarm and the fuse. Since the duration of this type of aluminum arrester is limited, it is necessary to take steps to remove the trouble as soon after it occurs as possible. This arrester may be located either in-doors or out-doors; and in order to make sure that the operator's attention will be called to the condition of discharge, an extra cell is placed in the arrester circuit near the ground and leads are carried from there to the office of the attendant or the superintendent. This bell begins to ring as soon as the discharge takes place over the arrester and continues to ring until the arrester ceases to discharge.

The arrester has a definite endurance to the discharge. Actual tests have been carried on to determine the life of a 13,000-volt arrester under different conditions. The arrester was caused to discharge in relays of two or three hours twice a day until the total time was 80 hours. The arrester was then dis-assembled and it was found that the plates were somewhat worn but the arrester was still in good condition. If the duration of each relay had been less than two hours, the wear of the arrester would have been very much less. It is estimated, however, that the summation of the total time of grounded phases on a system would hardly reach the value of eighty hours in many years.

Series fuses in each leg are introduced to meet two conditions. First, if for any reason the dynamic potential should be increased to a dangerous value, the arrester will discharge these heavy currents continuously until disconnected from the circuit. It is evidently impossible to use these lightning-arresters to discharge high dynamic current for any great length of time. Under normal conditions the dynamic current reaches a value of 0.4 ampere on 25 cycles, and 1.0 ampere on 60 cycles. Any current above these values is current coming from lightning surges. This current does not represent directly an energy loss because the aluminum cell is a fairly efficient condenser and the power-factor is correspondingly low. When, however, the dynamic current for any untoward reason rises above the critical film voltage the current is entirely energy current and the internal loss considerable. In this discussion only energy from the generator is being considered, and it is evident to any operator that if the potential on his line rises to such an abnormal value for any length of time all the lights on the system will be burned out and the motors be operated under abnormal conditions. The second condition which may arise to necessitate the disconnecting of the arrester from the circuit will be that due to the length of time the arrester is discharging more than that recommended as the limit. It may be noted, although the time recommended is only a half hour or a little greater for duration of discharge, in actual practice, the arrester has been caused to discharge repeatedly for two or three hours at a time. If one of these arresters is placed on the circuit and left there the discharge rate remains about 1.0 ampere until the arrester reaches the limit of its endurance. This as already stated depends upon the heating. The current rises rapidly and if the arrester is not disconnected, one cell after another will short-circuit, throwing each time the extra potential on the other cells until finally the condition of total short-circuit is reached. These arcs will tear holes in the aluminum and will reduce the stack of cones to their scrap value. If, however, a fuse of size amply large enough to take any induced stroke of lightning be placed in series, the fuse will still be small enough to disconnect the arrester from the circuit in time to save it for future use. In either event, whether the arrester is disconnected by the fuse or is destroyed by dynamic current, this point of the system is left without protection, but by the use of a fuse the arrester in test has been put back into the circuit again with no material damage other than the natural wear due to the passage of current.

This matter of the use of a fuse in connection with the gap-aluminum arrester has been treated at some length in order to show the difference in this practise between the application to the aluminum arrester and the multigap arrester. There are some justifiable objections to a series fuse with the multigap arrester which do not apply to the aluminum arrester.

Aluminum arresters for direct currents. These arresters are applicable to pressures from 110 to 1200 volts. The form of the arrester differs from the gap-aluminum arrester. Containing jars are used to hold the greater quantity of electrolyte and give greater cooling surface. The characteristics of this arrester differ in some details from the cone type previously described. The direct-current arrester has no series gap. It is connected to the circuit directly and has a small leakage current flowing through it constantly. In consequence of having no series gap its dielectric-spark-lag is zero.

A brief review of the practical properties of the 600-volt direct-current arrester is given below:

There is no series gap. The normal leakage current is 0.001 ampere. The discharge rate at double voltage increases a million fold, it is 1000 amperes. Internal resistance above the *permanent critical voltage* is a fraction of an ohm. It may be frozen. Its inductive length of circuit is small. Its equivalent-needle-gap is 0.00 in. as compared to other types of arresters which give 0.25 in. to 0.58 in. under the same condition of test. Its measured static capacity is equal to over 400 miles of trolley wire.

Temporary and permanent critical voltages. A condition which may be designated as a temporary critical voltage of the film valves is prominent in this arrester. If an arrester is on a 600-volt circuit taking one milliampere of current and the voltage rises to a slightly greater value, say 625 volts, the current will suddenly rise to several amperes. If the voltage is maintained, a thicker film is formed which again reduces the current to a few thousandths. If the voltage decreases again, this extra thickness of film is re-dissolved. The *temporary critical voltage* of the film then is the constant running voltage. From another point of view, this statement is equivalent to saying that the arrester begins to discharge at a high rate of current the instant the voltage begins to rise. This is in contradistinction of all gap types of arresters which do not begin to discharge until the spark potential of the gap is reached. The *temporary* is to be distinguished from the *permanent critical voltage* of the film. If the voltage impressed on this arrester should rise to about 840 volts the limit of film formation is reached. Every volt pressure rise above this value causes an increase of current which is permanent so long as the voltage remains constant. This passage of current through the film should be carefully distinguished from the usual failure of a dielectric. For illustration, a thin layer of mica may have several thousand volts impressed upon it before it disrupts. This disruption will take place at one point and the voltage will drop to about 50 volts which is the ordinary arc voltage. The aluminum film does not function this way. The exact physical phenomenon is obscure, but it is evident that there is no analogous drop of potential at the film when the heavy current discharges and furthermore the current is distributed over the entire surface.

The nature of the film varies with the electrolyte. As a working hypothesis it is assumed that it consists of pure gases in a liquid form held in a hard insoluble skeleton of aluminum hydroxide. This is borne out by most of the observed phenomena and so far as known is not disproved by any.

Earth Connections

The ohmic value of the earth resistance in connection with protective apparatus is usually unknown. The usual directions for making an earth connection are one or more of the following.

a. Bury a slab of copper about two feet square in coke.

b. Connect a wire to the water mains.

c. Locate a copper plate in the mud of a body of water.

The first is expensive to install, is concentrated at one point, and has an unknown value of resistance which may vary greatly from a change in moisture. The second gives a low value of resistance as a rule but is not available on lines and in many sub-stations. The third may give a low resistance but usually has an objectionably long earth connection.

With the object of learning the effect of distance between earths on the ohmic resistance, effect of the size of the earth plate, depth of conducting stratum and the most economical method of reaching it and maintaining contact, the writer has made a series of tests, several of which are given below. Some of these tests were begun in 1906 and continued to the present.

Methods. The first consideration was the choice of a method of test. The method employing the Wheatstone bridge recommended in some publications on telegraphy is unsatisfactory on account of the counter electromotive force of contacts. The simplest test is the measurement of voltage and current at the convenient value of 110 volts impressed and the only question regarding this test was the choice between alternating and direct currents. Alternating currents gave the most satisfactory results. If one volt counter electromotive force was subtracted from the impressed direct voltage the same resistance was obtained as given by alternating currents, except in one case. In this case the iron pipe was driven vertically through a deposit of coal ashes and cinders. At 1 ft. depth the direct-current method gave a resistance of 36 ohms whereas the alternating-current gave a resistance of 26 ohms. Since this deposit of cinders and ashes was not thick, its relative effect disappeared at a greater length of pipe. At a depth of 8 ft. the values by alternating and direct current sensibly coincided. This difference in resistance seems to have been due to some effect analogous to that in a coherer. The 110 volts of alternating current were obtained by transformation from 2300 volts; the high-potential static came through the particular transformer so badly as to make the handling of a low-voltage wire exceedingly disagreeable. This high potential may have caused the particles to cohere. The direct current was taken from a battery.

In all tests 1-in. iron pipes were used. The lettered pipes were 5 ft. and the numbered pipes 8 ft. in the ground. The resistances were measured between each pipe and the water-pipe main and also between earth pipes. The resistance of the water-pipe main was 3.3 ohms. The resistance of the earth pipes varied from 10 ohms to over 1000, according to the condition of the earth.

Fig. 20 shows the location of the earth pipes; numbers 1, 2, 7, 9, 3, 8, and 5 are on the same level in wet or moist ground. No. 4 is in a pine grove on an upper terrace eight feet above in dry earth and No. 6 is on a terrace ten feet below in very wet earth. The distances between earths: from 2 to 7 is 5 in. (probably not accurate to 8 ft. depth), 7 to 9 is 1.6 ft., 9 to 3 is 4.75 ft., 2 to 3 is 6.5 ft., 2 to 8 is 33 ft., 2 to 9 is 1.9 ft., 3 to 7 is 6 ft., 2 to 5 or 6 is 650 ft. Pipe earths *B*, *C*, *D*, *E*, and *F* were given special treatment to increase the conductivity of the earth near them.

Resistance per foot depth of pipe. The curves, Fig. 21, show the resistance of each earth pipe at each increase of one foot depth. The water main is designated as *G*. *G*-1 means that the two are used as electrodes. The first measurement taken was with the

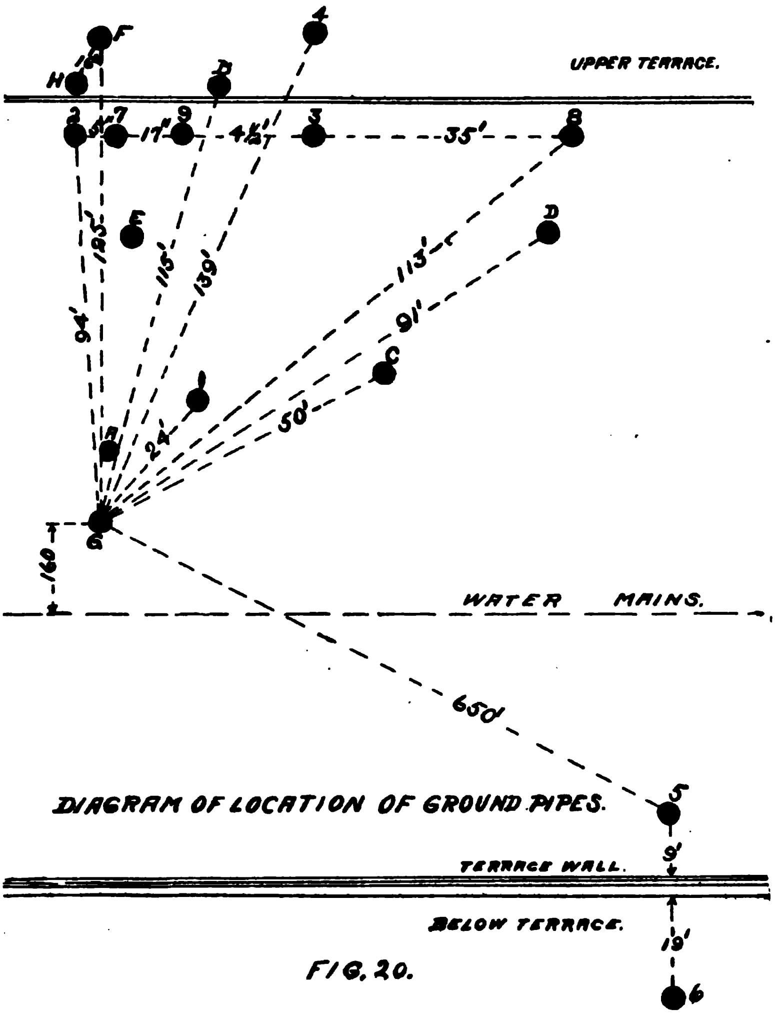


FIG. 20.—Map of earth pipes at the laboratory

pipe resting on the surface of the earth. The resistances of these various connections varied from 1000 to 8000 ohms and cannot be shown on the scale of the print. The curves show that pipe No. 1 was well into the conducting stratum at 1 ft.

depth; Nos. 2 and 3 at about 2 ft. depth; No. 6 below the wall at about 3 ft. and No. 4 on the dry upper terrace had to be driven about 7 ft. before it penetrated the conducting stratum. No. 5 at 8 ft. depth is equal in resistance to No. 1 at 1 ft. depth only.

Comments on the change of resistance per foot. From the curves of Figs. 21 and 22 one may conclude that in making a pipe ground there is little to be gained in conductivity in driving a pipe more than 3 to 6 ft. into the conducting stratum. Com-

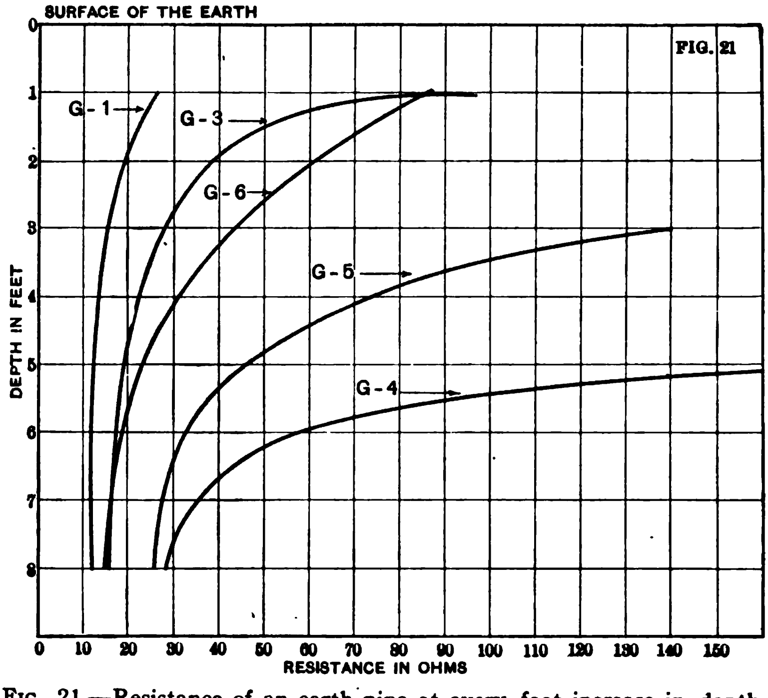


FIG. 21.—Resistance of an earth pipe at every foot increase in depth

paring the resistance between pipes 2 and 1 at different depths it will be seen that at the surface the resistance decreases in proportion to the depth but already at 2 ft. depth the area or depth is increased 100 per cent. over 1 ft. yet the resistance decreases only 46 per cent. The ratio of these percentages is roughly 2½. Between 7 and 8 ft. the area increases 14 per cent. but the resistance decreases only 3.4 per cent. The ratio of these percentages is roughly 4. In other terms the resistance is only decreasing one-fourth as much as the area is increasing. In fact this curve is logarithmic and theoretically nearly reaches zero resistance when the pipe is infinitely long. Since the specific resistance of the earth varies with the depth the equation of the curve is not simple. There are two parts to it. The equation for the greater depth is $f = 100\ (k-b)^{A}$

Between pipes Nos. 2 and 1 the numerical values are:

$$f = \text{feet depth},\ k = \frac{1}{\text{resistance}},\ b = 0.0035 \text{ and } A = 2.$$

Fig. 22 shows the resistance of each pipe earth relative to and including No. 2.

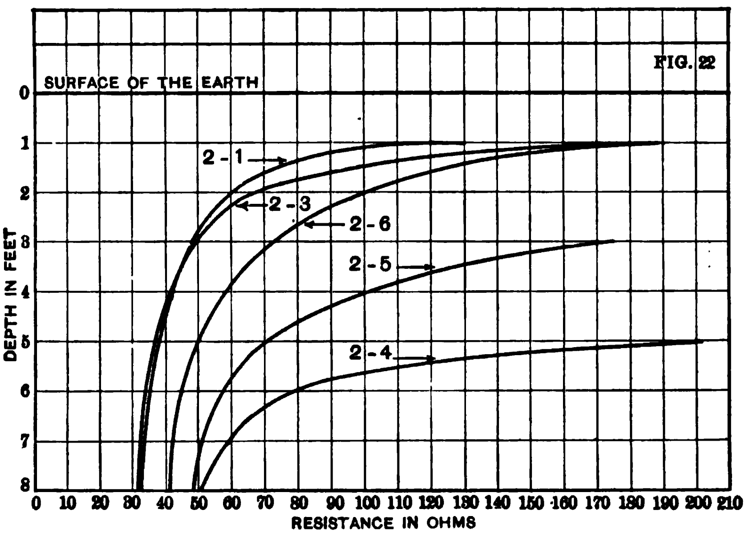


Fig. 22.—Resistance between pairs of pipes at every foot increase in depth

Effects on the Resistance of Varying the Distance Between Earth Pipes

The desideratum is to determine what distance apart pipes must be placed to give practically the maximum possible resistance. It is a well known fact that after a certain distance between earths is reached any further increase in distance will not increase the resistance between them. Fig. 23 shows the resistance taken between pipes set at various distances. The resistance reaches a nearly constant value at about 6 ft. separation. Therefore if it is desired to place a ground resistance in series between phase and phase of a line as suggested by Dr. C. P. Steinmetz some years ago, it is necessary to separate the ground pipes only by this distance. In other words it is not necessary to make one at one pole and another at the next pole.

Treatment to improve earths. The material of the earth in this locality seems to be a mixture of clay and sand. Five pipes having a length of 5 ft. each were used in this test and are designated by the letters *B*, *C*, *D*, *E*, and *H*. The variable resistance of each of these earths relative to time, is shown in Fig. 24. Tests were made for eight consecutive days.

Earth *B* was made by digging a post hole and mixing the dry earth with 16 pounds of salt and pressing the mixture back into

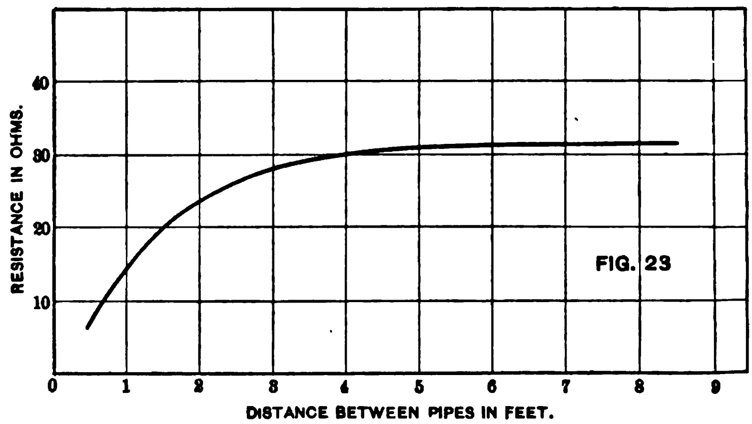


FIG. 23.—Resistance between pipes with the distance between them variable

the hole around the pipe. Water was then poured around the top of the hole. This pipe was located on a projection of the terrace, 8 ft. high, so that there was a sudden drop on one side of 8 ft. and on the other side a drop of 4 ft., to a ditch. The resistance of the earth decreased daily showing that the salt water was percolating from the dry earth of the knoll down to a conducting stratum about 3 ft. below the pipe. During the eight days water was poured onto the top of this earth four times. It has now stood one year and seven months and the ohmic resistance has not varied materially.

Earth *C* was made by digging a post hole, pouring into this hole sixty pounds of lime, sixty gallons of water, and filling in with dirt around the pipe. The location of this earth was below the terrace in good ground. Earth *C* is located quite near the previous mentioned earths designated as 2, 7, 9, and 3, and this treatment added nothing to the conductivity of the already moist earth.

Earth *D* was formed by simply driving a pipe 5 ft. into the earth, cupping out around the pipe at the top. Four pounds of salt were then placed in this cup and water was added. Twice subsequently, water was added. Results are shown by the curve.

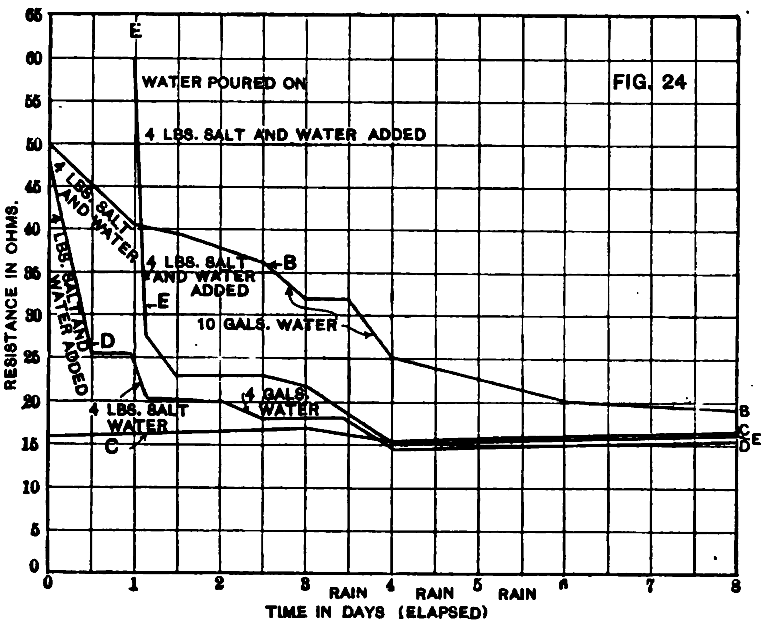


FIG. 24.—Decrease of resistance versus time after pipes have been treated with salt water

Earth *E* was formed by laying a pipe on the level ground and covering with earth. Salt was then scattered over the earth and water poured on the mound. In this case fairly good conductance was obtained 1 ft. below the surface. This fact is indicated in the curve sheet by the sudden drop in the resistance from 60 ohms to 26 ohms during the same day.

Earth *H* was formed by laying a pipe horizontally in a shallow ditch and covering with earth. Fourteen pounds of salt were mixed with the earth and then water poured over all. This earth was located on the edge of the upper terrace which is 8 ft.

high. The initial resistance before water was added was 545 ohms. After two and one-half gallons of water were added, the resistance dropped the same day to 87 ohms. Water was added each subsequent day and after six days the resistance had gradually dropped to 25 ohms, (these results are not shown in Fig. 24). They are most remarkable, however, in that the salt solution had to percolate about 8 ft. before it struck a stratum of good conductivity. After one year and seven months the rain has washed out some of the salt from the covering of dirt about one inch deep, and the resistance has risen, but it is still less than one-quarter its original value.

The conclusions drawn from these tests are that the conducting stratum of earth can be reached and maintained by

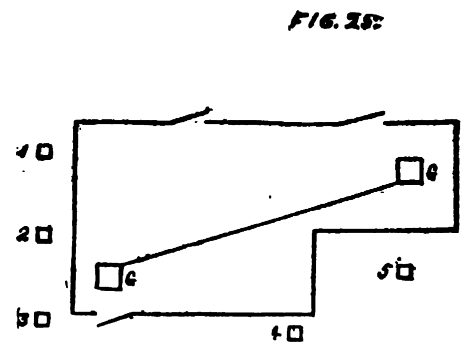


FIG. 25.—Map of earths at the sub-station of the Animas Power and Water Company

the addition of salt and water around the pipe. It is reasonable to infer that if the soil is sandy a greater amount of salt would have to be added. The salt in itself is hygroscopic and will always retain a certain percentage of moisture. In localities where the rain washes the salt through to the conducting stratum rapidly, it will be advisable to add salt at least once a year.

Multiple pipe earth connections. The same set of pipes (2, 9, 7, 3, and 8) used to obtain the variation of resistance with the distance between electrodes, was also used to get the variation in resistance, by putting the different ones in parallel. Numbers 2 and 7 were driven 5 in. apart. There is no material variation in the resistance of these two earths, whether multiple or singly—the value is about 16 ohms to the water main. If, however, No. 2 is combined with No. 3, which is 6.8 ft. away in a line parallel to the water main, the resistance of the two in multiple is only 10.7 ohms. The data are:

$G+(2)$	= 16	ohms.
$G+(7)$	= 15.9	"
$G+(2, 7)$	= 16	"
$G+(3)$	= 19.3	"
$G+(2, 3)$	= 10.7	"
$G+(8)$	= 21.6	"
$G+(2, 8)$	= 9.8	"
$2+(3)$	= 28.7	"
$2+(7)$	= 0.755	"

By algebraic combinations, the calculated resistance and conductance of each pipe is found.

Pipe No. 3 =	16	ohms	= 0.0625 mhos
" No. 2 =	12.7	"	= 0.0787 "
" No. 8 =	18.3	"	= 0.0547 "
Water main No. 9 =	3.3	"	= 0.3030 "

If these resistances are combined by the ordinary rule for parallel resistance, the values are different from the measured ones.

By formula Nos. 2 and 7 in parallel is 8 ohms, but measure 12.7.

By formula Nos. 2 and 3 in parallel is 7.07 ohms, but measure 7.4.

By formula Nos. 2 and 8 in parallel is 7.5 ohms but measure 6.5. Inci'entally, the last reading is in error due to leaving the current on too long. Later it will be shown that when a pipe earth rests after carrying dynamic current for a while, the conductance increases.

General law for pipe earths in parallel. In order materially to reduce the resistance of a pipe earth by additional electrodes, the added pipe must be driven out of the denser stream lines of current of the pipes already driven. As example, No. 7 was driven in the dense stream lines of No. 2 and did not lower the resistance by a measurable value whereas No. 3 was pretty well out of the stream lines and nearly follows the well known laws of paralleling resistances. Figs. 26, 27, 28, and 29, show the stream lines for various conditions; Fig. 26, vertical pipe and water main; Fig. 27, horizontal current lines between two vertical pipes; Fig. 28, roughly the vertical cross section of current stream lines between two pipes partially driven. The two logarithmic factors are represented, one by the straight lines and the other by the curved lines—Fig. 29, current stream lines of a pipe touching the surface. The similarity of these current lines to the static field around a charged conductor is evident, in fact if the earth is assumed to have uniform resistivity, the

FIG 26

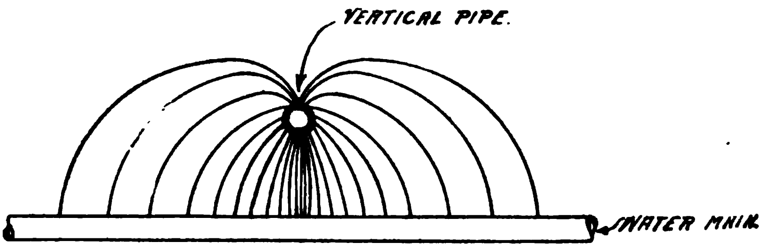


FIG. 26.—Current stream lines between a vertical earth pipe and a horizontal water main. They are similar in form to a static field

laws are almost identical. As an example of the relation, the capacity of a single conductor 0.18-in. diameter and 75 in. from the earth is 0.0169 microfarads and the capacity of a conductor twice the diameter is only 0.0195 microfarads; in other words, an increase in size of 100 per cent. increased the dielectric displace-

FIG. 27

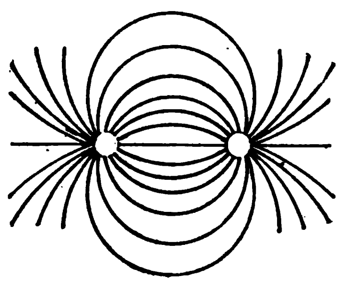


FIG. 27.—Current stream lines (horizontal section) between two vertical pipes

ment current only 15 per cent. If the earth pipe is driven several feet to minimize the proportional effect of the tip and lines represented in Fig. 29, the same law should hold approximately true for dynamic current as for displacement current; consequently with one earth pipe resistance known, the resistance of a pipe of different diameter may be estimated from appropriate tables of static capacity. Returning to the static analogy, if another line wire 0.18 in. diameter is strung parallel to the first at a distance of a few feet, the capacity of the two in parallel is twice 0.0169 microfarads. Analagously, the conductance of two earth pipes is increased.

Values of resistance of the condition of the pipe touching the surface (Fig. 29) are herewith given on account of their relation to a broken line wire touching the ground. Pipe No. 1 was 1200 ohms, No. 2 was 1260 ohms and No. 4 was 6000 ohms.

FIG. 28.

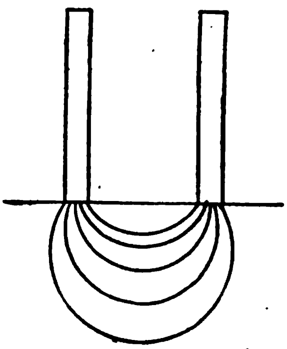


FIG. 28 a.

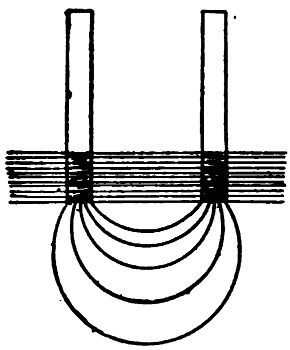


FIG. 28.—Current stream lines (vertical section) between two vertical pipes touching the surface of the ground

FIG. 28 a.—Current stream lines (vertical section) between two earth-pipes partially driven. The two sets of lines represent the two logarithmic factors of the equation of the resistance

In connection with the subject, the drying out of the earth by dynamic current as given later should be noted.

Animas earth tests. These tests of earths around the laboratory were supplemented by measurements of earths on the Animas Power and Water Company's system. Fig. 25 is a map showing the location of the earths at the sub-station near Silverton. The ground in this locality is principally the gravel washed down from the steep mountain sides. The Animas River flows past the sub-station at a distance of about 100 yards. Under the station floor at the two points shown are two of the old type grounds consisting of expensive copper plates buried in coke. These two together are designated as G in the notes. Around the building five iron rods were driven to a depth of 6 ft. entailing unusual trouble on account of the stones encountered. The tests are divided into six parts.

1. *Variation of resistance with depth (dry earth).*
2. *Variation of resistance with time after salting.*
3. *Measurements of resistance between pipes in variable multiple groups.*
4. *Measurements of resistance between the sub-station and Hobbs' Switch,* 5.5 *miles up Gladstone Canon.*
5. *Measurement of resistance between sub-station and power house* 25 *miles down the Animas River.*
6. *Measurements of resistance of tree earth, pole earth, railroad earth, and side hill earth.*

Variation of resistance with the depth as the iron rod was driven. All measurements made with the lighting voltage (125 volts approximately). Pipe No. 3.

Depth in feet	Resistance in ohms
1	604
2	172
3	250
4	312
5	125
6	161

The irregular variations are due to the lateral displacement of the iron rod as it pushed by some obstructing stone.

Time resistance variation after salting the rod at the surface of the ground.

Time in minutes	Resistance in ohms
0	161
5	62.5
10	47.7
30	38.5
360	33

This earth was located at the corner where all the rain water from the roof was carried. A storm occurred and considerable water was discharged around the pipe. Enough of the salt was washed through the gravel to raise the resistance from 33 to 35 ohms. The other earths were unaffected by the rains.

Measurements of resistance between pipes and various multiple groups.

Earth pipes	Resistance in ohms	Pipes in multiple	Resistance in ohms
1 to 3	128	*G* to 1, 2, 3, 4, 5,	32.3
2 to 3	64	*G* to 1, 2, 4, 5,	36.6
4 to 3	128	*G* to 1, 2, 3, 4,	35.
4 to 3	115	*G* to 1, 2, 3,	37.1
3 to 5	107	*G* to 1, 2,	47.4
G to 5	85	*G* to 1, 5,	53.2
G to 1	115	*G* to 1, 3, 5,	39.4
G to 2	55.5	*G* to 2, 3,	39.4
G to 3	57.		

The individual resistances can be found by elimination in the algebraic equations, but the resistance of any earth pipe is not a constant; it depends on its relation to the other electrode. This is treated later. The values calculated are:

$G = 22$	ohms	$= 0.0455$	mhos.
$1 = 93$	"	$= 0.0107$	"
$2 = 31.25$	"	$= 0.0320$	"
$3 = 35$	"	$= 0.0286$	"
$4 = 93$	"	$= 0.0107$	"
$5 = 67.5$	"	$= 0.0148$	"

By summation of the reciprocals the calculated values of resistances of the pipes in various combinations are:

1, 2, 3, 4, 5,	= 10.3 ohms	= 0.0968 mhos.	*G* by subtraction from tests = 22
1, 2, 4, 5,	= 14.7 "	= 0.0682 "	" " " " " = 22
1, 2, 3, 4,	= 12.2 "	= 0.0820 "	" " " " " = 22.8
1, 2, 3,	= 14. "	= 0.0713 "	" " " " " = 23.
1, 2,	= 23.5 "	= 0.0427 "	" " " " " = 23.9
1, 5,	= 39.2 "	= 0.0255 "	" " " " " = 19.
1, 3, 5,	= 18.5 "	= 0.0541 "	" " " " " = 21.
2, 3,	= 16.5 "	= 0.0606 "	" " " " " = 22.9

Two salient features of these tests are: first, the low total resistance of the five pipes in parallel (10.3 ohms) as compared with the two station earths (22 ohms); second, the low cost and the easy and certain maintenance of the pipe earths as compared to the old type earths. The pipe earths are to be preferred, from every point of view.

Measurements of resistance between the substation and Hobbs' switch, 5.5 miles up Gladstone Canon. Three earths were made at Hobbs' switch and by means of the telephone wire connections were made between these earths and the earth (G) at the sub-station. No suitable measuring instrument was at hand so a voltmeter was used. The results are less accurate than the previous tests. In calculating the individual earth resistance the assumption was made that each earth carried a local value of resistance and that the rest of the resistance was in the main body of the earth between, or since there are mountains of granite in direct line between the two stations, that there was a resistance of the surface of the earth down one cañon to the fork and up the other, quite distinct from the local resistance. The calculated results seem to justify the assumption in this particular case. The Hobbs' earths were not salted and were made in ground through which snow water was percolating, consequently their resistances are high. The following values were obtained: Hobbs No. 1-437 ohms; Hobbs No. 2-100 ohms; Hobbs No. 3 (ground for telephone) 189 ohms; and the resistance of the telephone wire plus the 5.5 miles of earth between stations was 89 ohms. Subtracting the telephone wire resistance leaves the 5.5 miles of earth 36 ohms. The resistance to a lightning discharge passing along the wires cannot be less than this and is probably much greater.

Measurement of earth resistance between the sub-station and the power house, 25 miles down the Animas River. The total resistance, including both station grounds, the earth between and the line wire, was 55 ohms. The resistance of the power house earth plus the main body of earth was only about 30 ohms which is less than the main body of the earth to Hobbs' switch.

Measurement of the resistance of tree earth, side hill pipe earth, pole earth and railroad earth. Up on the gravelly hill side about 100 ft. above the substation was an evergeen tree. A line of nails was driven into the tree just above the ground and wired together. Six feet higher another set of nails was driven. The tree at the base is 5 ft. in circumference and at 6 ft. up is 4 ft. in circumference. Resistance of the base of the tree to station earth is 770 ohms and from the point 6 ft. up is 2820. Resistance per foot height of tree 340 ohms. An iron pipe driven 5 ft. near the tree measured 353 ohms dry and 190 ohms a short time after it had been salted down and wet with a bucket of water.

Seven nails four inches long were driven around the circumference of a spruce transmission pole just above the ground.

The pole stood on a level with the sub-station. The resistance to the sub-station earth was 1290 ohms; 14 in. higher up it was 3300 ohms. Seven more nails were driven at the same height

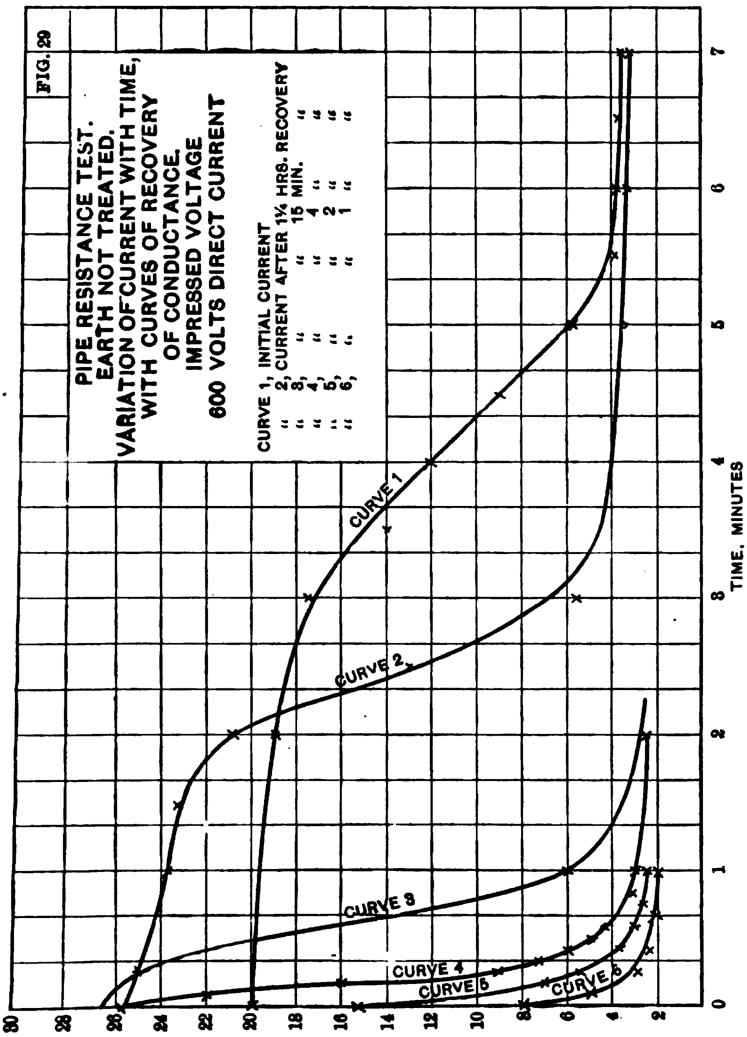


FIG. 29.—Curves showing the energy capacity of earth pipes, also curves of recovery of conductance
Earth not treated

to increase the area of contact. The resistance from the ground surface dropped to 980 ohms and correspondingly at 14 in. up it dropped to 2700 ohms. This gives about 1450 ohms per foot. At 6 ft. up, however, the pole was so dry that its resistance was too high to measure with a voltmeter having a scale of 150 volts and an internal resistance of 5200 ohms. The low resistance at 14 in. up shows the effect of capillary attraction in drawing up the moisture from the ground.

A resistance measurement was taken between the steam railroad track which parallels the main transmission line 35 miles and the sub-station earth No. 3. The total value was only 46.5 ohms which leaves 11.5 ohms for the railroad.

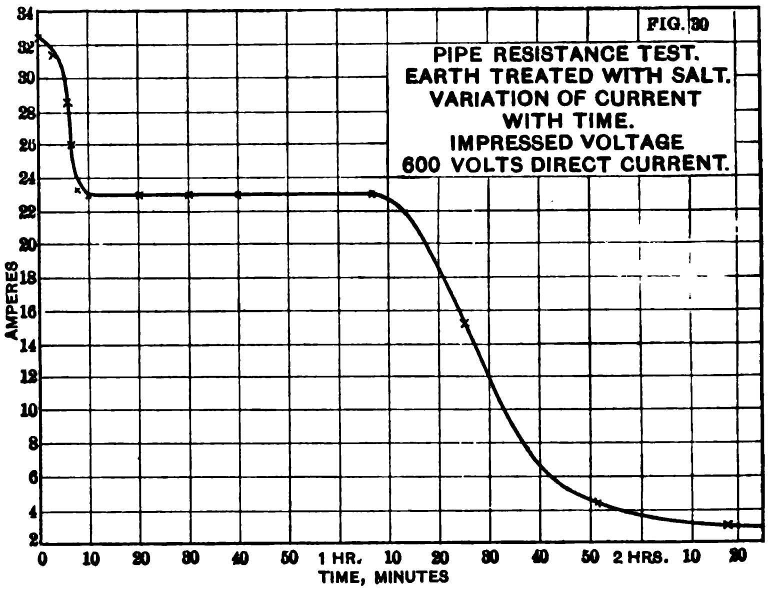


FIG. 30.—Curve showing the energy capacity of the same earth pipe salted

EARTHS CARRYING DYNAMIC CURRENT

Variation of earth contact resistance when dynamic energy is applied. Occasionally dynamic energy is passed through the earth connection. This may occur: first, when arresters connected to different earths operate simultaneously; secondly, when a phase of a grounded neutral system is accidentally grounded; thirdly, to a less degree, when a phase of a nongrounded neutral system is accidentally grounded: and fourthly, when single-phase arresters are used connected to different earths.

A study of the effect of dynamic energy was made on pipe earth No. 1 near the laboratory, under the two conditions of unsalted and salted. The pipe was 1.25 in. outside diameter (known as inch pipe) driven to a depth of 8 ft. 600 volts direct

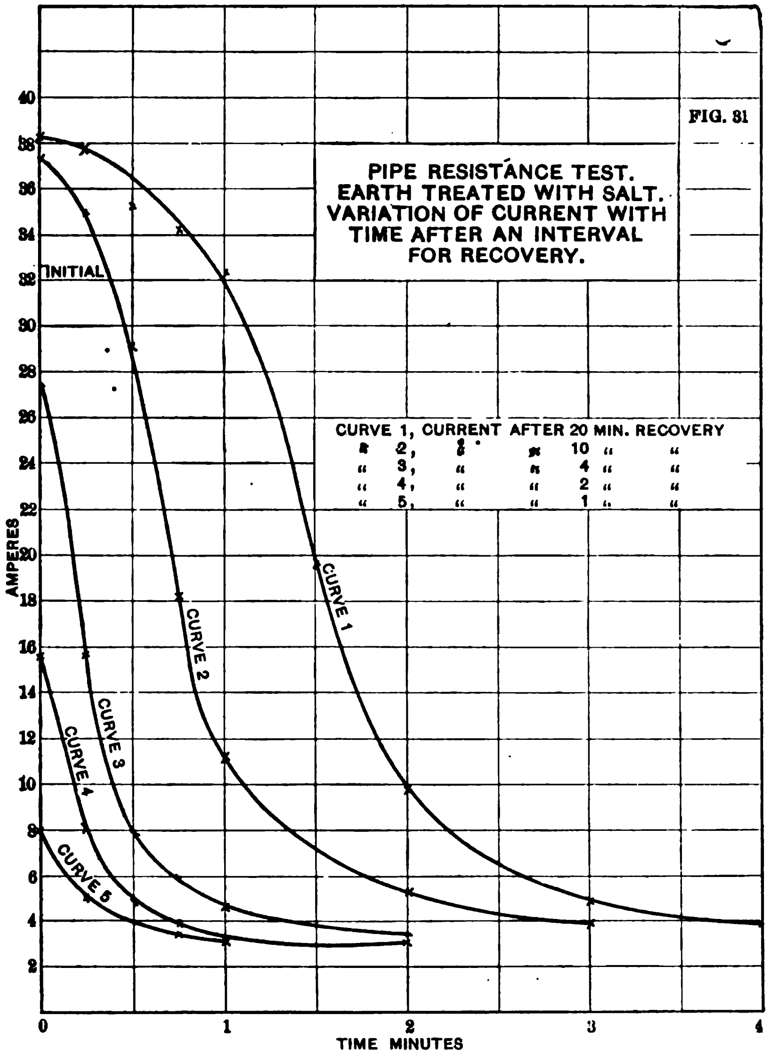


FIG. 31.—Curves of recovery of conductance of the same salted earth-pipe

current potential were impressed. The results are shown in the three curve sheets Figs. 29, 30, and 31. Fig. 29 gives curve of the unsalted earth and Figs. 30 and 31 of the salted earth.

The characteristic behavior was the same. At first there was a fairly steady current flow until the temperature increased sufficiently to make the pipe steam and boil away the moisture, then secondly, a rapid drop of current to a fairly constant value such that the moisture was supplied from the surrounding earth as rapidly as it was evaporated. This supply of moisture could go on indefinitely only if the pipe were driven into a sink or a subterranean stream. Thirdly, when the potential is removed there is a rapid recovery of conductance. Fourthly, there is finally, after a few minutes repose, a higher conductance than existed initially.

Between the unsalted and the salted earth there is a marked difference in the endurance or kilowatt capacity. The unsalted

FIG. 32.

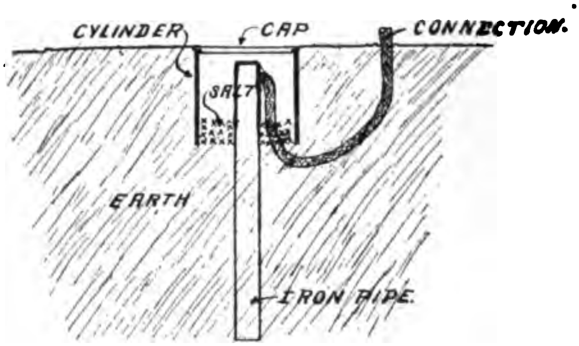


FIG. 32.—A recommended form of pipe earth unit

earth carried 20 amperes for 3 min. (12 kw. for 3 min.) before it began to lose its conductance, whereas the salted earth carried 23 amperes for 70 min. (13.8 kw. for 70 min.) which is 20 times as much. The unsalted test was made one day and the pipe was then salted down and left until the following day, about 18 hr. While the salted earth was being tested chlorine gas was given off.

Form of pipe earth recommended. Any kind of metal pipe or rod driven into the earth a few feet makes a good earth connection if the soil around the pipe at the surface is cupped out, filled with a few pounds of salt, and water added. A neater form of earth unit is shown in Fig. 32. A cylinder of metal or earthenware of any available diameter is set around the pipe at the surface of the ground and covered by a lid. This receptacle will hold the salt. Its advantages lie in the easy inspection of the connection and protection of surrounding vegetation from the saline water.

Last year it was proposed to draw some distinction between the general use of the words "ground" and "earths" as a matter of convenience and clearness; for example, a lightning-arrester may be grounded to a cable sheath or a transformer case and still be not earthed at all, unless these parts should be earthed; on the other hand, the arrester may be grounded to a pipe earth or to a system of pipe earths. This distinction will be somewhat justified in the grounding methods described in the following.

It has always been customary to speak of a low-resistance earth as advisable and necessary to the proper functioning of a lightning-arrester. Obviously, this is not always true. It is true as a protection to insulators but not so as a protection to isolated apparatus. While it is not the object of this paper to encourage the use of high-resistance earth, a method of grounding will be shown that does not diminish the protection in spite of a high-resistance earth connection. There are three factors involved which require separate treatment; namely, (*a*), the resistance factor; (*b*), the inductance factor; and (*c*), the permanence.

Station grounds. a. The resistance factor. The object of protective apparatus is not to prevent a rise in potential but to prevent an increase in difference of potential between the line and metal bodies or cases. To accomplish this the lightning-arrester must limit the potential between its terminals; at its lower terminal it should be connected to the metal cases of the apparatus and to a system of pipe earths encircling the station. If the resistance of the pipe earths is so high as to limit the discharge, there will be a drop of potential from the outside of the station to the point under the line whence the charge came. The potential of the station may actually rise momentarily thousands of volts above the surrounding country, but this is of no consequence because the potential of everything in the station rises simultaneously.

There is one source of danger which should be avoided. If a water main runs into the station it should be connected to the multiple pipe earth, because if its resistance is low compared with that of the pipe earth a person could get a shock from a charge passing from the station into the water main. If it were not for the danger of the water main, a fairly high resistance of multiple pipe-earths would be advantageous in using up the energy of the lightning stroke without risk of the $I R$ drop causing a dangerous difference of potential. In isolated stations where there is nothing corresponding to a water main, multiple pipe earths around the building connected to the transformer cases should be sufficient. That is to say, a long lead running to the mud of an adjacent stream is needless.

The bearing earth connection resistance has on the protection of insulators, so far as known, may be theoretically explained. The only protection there is for an insulator is a lightning-arrester placed in the region of induced static from the clouds. The station arrester acts as a protection to insulators only when the inducing cloud is over the station. If the resistance of the multiple pipe earth is high it will, in the latter case, give theoretically a somewhat less protection to the neighboring insulators. Since salted multiple pipe earths, even under the very worst conditions, give lower resistance than the old method earth, there is no choice between them.

b. The inductance factor of earth connections. Since the resistance factor is brought to a matter of indifference by the multiple pipe earths, the inductance factor should be considered. It was feared that the iron pipe would offer greater inductance to high frequency currents than copper wire. Dr. C. P. Steinmetz has made calculations which show that the pipe is actually a better conductor of high frequencies than a large copper wire. Regarding the connections between a lightning-arrester and earth the rule has always been to make it as short as possible. It is advisable to drive a pipe earth directly underneath the arrester even if such earth must be of relatively high resistance. This earth should be connected to the other earths. A more general rule is: make the circuit between the line and earth through the arrester short relative to the length around through the apparatus to the earth. A choke-coil gives considerable added length. While this precaution may not be followed rigidly in high-tension apparatus, it seems to be extremely important in low-tension apparatus, especially with railway motors. Double-cotton-covered wire is delicate insulation. Some concrete ideas of what is possible if a storm cloud is over a trolley line may be gleaned from laboratory tests. With two leyden jars of the gallon size, giving a frequency of about two million cycles per second and a momentary current rush estimated at

1000 amperes, the potential drop along one foot of No. 10 B. S. wire will puncture the insulation between two wires, each double-cotton-covered; that is, four layers of cotton covering. The shortening down of the lightning-arrester circuit to the last possible inch may seem over cautious. With the old types of lightning-arresters which contain an appreciable internal resistance it is needless precaution, but the new aluminum arrester for railway circuits has an equivalent-needle-gap of 0.00 inches, an inductive circuit of only a few inches, internal resistance of only a fraction of an ohm, no series gap and a discharge rate of over 1000 amperes at double line voltage. Its normal leakage current is only about one millionth of this or 0.001 ampere.

While this arrester is designed to take care of the severest induced strokes it cannot of course prevent a drop of potential along its connecting lead. The ideal connection of this arrester to a trolley car consists in a lead carried from the trolley down near the motor or truck frame, connected to the lightning-arrester, and then carried back, not in the same conduit, to the car wiring. Nearly all the types of car wiring give this condition with varying degrees of perfection. While in most localities the lightning troubles encountered may not warrant the expense of rewiring, it is important to examine these features when the aluminum arrester is used in localities where the lightning is especially severe and frequent.

So far, only the length of lead has been considered. It is sometimes impossible to shorten a lead below a given length and still important to reduce the impedance of it. Since the smallest wire that will carry the dynamic discharge of an arrester has a negligible ohmic resistance, the shape of the conductor only need be considered. Theoretically, the inductance decreases nearly in proportion to the increase in metallic surface.* The equivalent-needle-gap, however, shows a less gain as the surface increases. The following measurements give relative concrete values of potential drop under nearly the same condition as that noted just above. A 5 ft. length of copper ribbon 2.5 in. wide and thin as paper was connected in series with an equal length of No. 10 B. & S. wire. The equivalent-needle-gap of the strip was $\frac{3}{16}$ in. (0.476 cm.) and of the wire $\frac{7}{16}$ in. (1.11 cm.). The potentials corresponding to these values of needle-gap are 3760 volts and 8750 volts effective—about two and one-

* C. P. Steinmetz and K. Ogura, "Inductance of Straight Conductors".

fourth times as great. Using peak values, the potential drop per foot along the wire was 2470 volts.

From the known data a value of current may be obtained by substituting in the equation $E = L\omega I$. The frequency was two and one-quarter million cycles per second, consequently the current must have been greater than 550 amperes. A partial check on this value may be made by assuming zero resistance and calculating the current by the previously given equation involving the total circuit.

$$I = V\sqrt{\frac{C}{L}}$$

By this equation the maximum possible momentary value of current in this circuit is 3000 amperes at 100,000 volts impressed potential.

The foregoing calculations indicate that a discharge of current and frequency so high will tax both the resistance and the inductance limitations of an arrester to the utmost. The practical question yet to be answered is when and how often may these conditions arise? A speculation is useful to the observer and student of this phenomenon.

First of all the conditions may be obtained when a direct stroke hits the line; but such a discharge does not, in general, reach the lightning-arrester. It is probable that it may happen to a degree when a car or station is underneath a thunder cloud which discharges to the earth. It seems quite certain that it cannot happen from a traveling wave along the line because of the relative valve of the inductance of the line to the capacity. It seems safe to presume that the combination of high frequency and large current occurs infrequently at an arrester.

The permanence factor of earths. The permanence of the conductance depends on the moisture. Tests have been made using 600 volts on a pipe earth to drive out the moisture. In this case there was no baking of the material surrounding the pipe and consequently there was a quick recovery of conductance. No tests with more power and higher voltage have been made and possibly a more lasting effect might be produced by a grounded phase on a grounded neutral system. If such occurred during a storm the multiple pipe earths would be especially valuable.

Lightning conductors for the protection of buildings. The customary lightning conductor is usually connected to a single earth by a single conductor. Numerous cases of side flashes from the rod into some part of the building have been recorded. The following recommendations based on minimum inductance and screening are made:

Assuming a pointed roof for simplicity of illustration, a rod should be carried up high enough to act as an electrode for the lightning arc probably six feet or more, basing the distance on photographs of the part of the rod rendered luminous by the lightning. From a point about midway up on this rod, at least eight copper or iron wires should be attached; a wire passes to each corner of the roof and one at each mid-point. Each wire is carried directly down to a salted pipe-earth. At the eaves a horizontal metallic connection should be made to equalize the potentials and again at the ground line. The natural inclination of high frequency currents to spread over a surface will tend to prevent a side stroke toward the interior of the building. The multiple earth will tend to equalize the potential over the entire building. With a given amount of copper, the more it is subdivided into multiple paths, the surer the protection.

The foregoing is intended to cover only the principle involved and will have to be altered somewhat to meet architectural demands.

Cement as a Resistor.

Some time ago the possibilities of trouble with lightning-arresters on a system using cement resistors between the neutral of the system and ground suggested the necessity of studying its characteristics. It may be noted in passing, that arresters for non-grounded neutral systems require an extra leg between the multiplex connection and earth to limit the dynamic potential across the arrester in case of an accidentally grounded phase. If the resistance in the neutral rises appreciably, the condition is equivalent to a non-grounded neutral system.

Another important phase of the subject is related to the use of cement in poles and as anchors or foundations for electrical transmission towers. In the event of a shattered insulator, the cement or concrete will be called upon to carry either the charging current or one phase according to the connections. In this case the question of conductivity is a minor matter and attention should be directed to the possibility of disintegrating the cement by overheating. A series of tests was carried out to determine the characteristics to apply to the foregoing problems. The writer is indebted to Mr. R. H. Marvin for the tests. The report is so replete with data and conclusions it is given verbatim.

These tests were undertaken to determine the suitability of portland cement as a material for resistances, especially its use with large currents and on high voltages.

They tend to show the following conclusions.

At moderate temperatures the resistance depends simply on the amount of moisture in the cement and becomes extremely high if the moisture is removed, either by long drying or artificial heating. The addition of sand increases the resistance, acting apparently as an insulator distributed through it. When cement is heated it at first increases enormously in resistance as the moisture is driven off, but at a red heat it again becomes as good a conductor as when cool and damp. With the same voltage per unit of length, a moderate voltage, as 600 volts, will not heat the material above 100° cent. so as to pass the interval of high resistance; but a higher voltage, as 8000 volts, can pass this interval and heat the resistance to incandescence.

The subject will be treated under the following heads:

1. Effect on resistance of cement of various proportions of sand.
2. Change in resistance with age.
3. Behavior of cement resistances on constant potential circuits.
4. Effect of moisture on resistance.
5. Conductivity at high temperatures, or pyro-conductivity.
6. Change, from conductivity due to moisture, to pyro-conductivity with high voltages.
7. The properties of cement as a resistance when used in the form of concrete.

Subjects 1 and 2 are naturally included in the same tests and will be treated together.

1 and 2. *Effect on resistance of cement of various proportions of sand, and change of resistance with age.* Resistances were made up in the form of rods of square section. These rods were 14 in. long and had a cross-section approximately 2 in. by 2 in. or 4 sq. in. At 1 in. from each end, sheet iron terminals were inserted while the cement was soft. These terminals consisted of a strip of 17 mil. soft sheet iron, 2 in. wide and 2.5 in. long with a projecting lug for attaching a wire. The strip was slit for 2 in. into eight strips 0.25 in. wide; each 0.25 in. strip was then twisted through a right angle, giving a fork like appearance. This terminal gave a large area of contact without mechanically weakening the block. The terminals were thus 0.25 in. long in the direction of the axis of the rod, but in obtaining the specific resistance their distance apart, center to center, or 12 in. was taken.

The materials used were:

Edison portland cement and ordinary building sand.

Five different mixtures were tried, six rods being made of each. The materials for each set of six rods were mixed together so as to insure uniformity. The proportions were as follows, in parts by weight.

Set *A*. Cement 1 Water 0.3
Set *B*. Cement 1. Sand 1. Water 0.45
Set *C*. Cement 1. Sand 2. Water 0.74

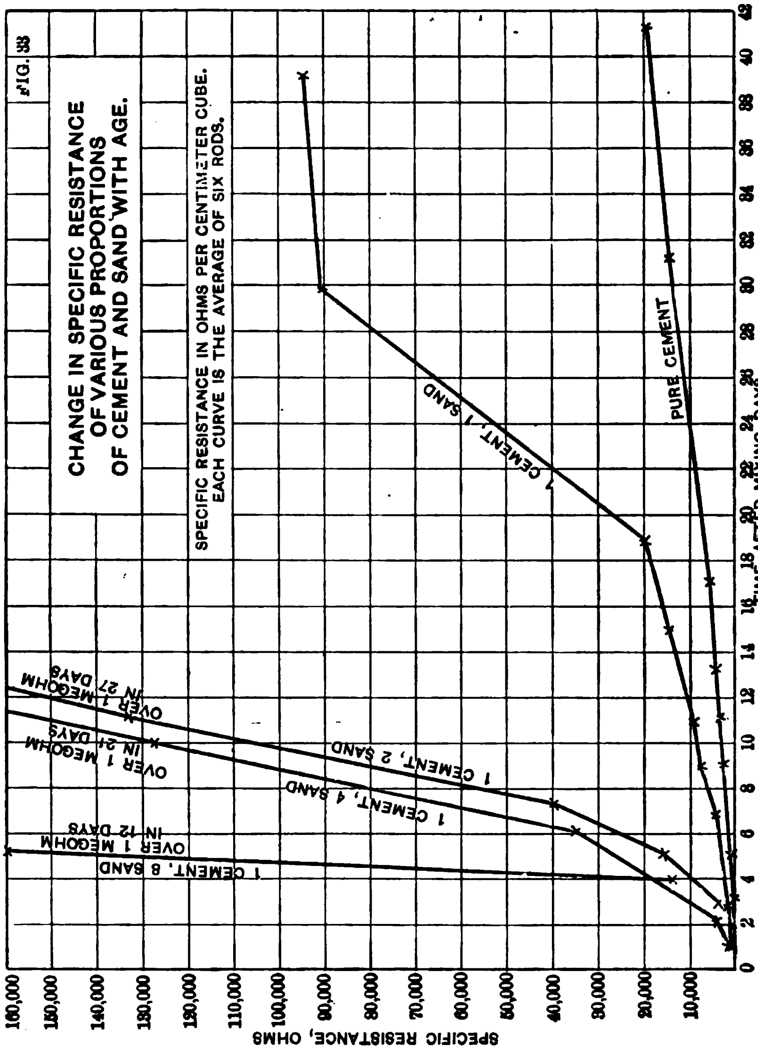


FIG. 33.—Time versus resistance of cement and sand

Set *D*. Cement 1. Sand 4. Water 0.58
Set *E*. Cement 1. Sand 8. Water 1.57

The rods of set *E* having such a large proportion of sand were very fragile for sometime after mixing, and never became very strong.

The resistance was measured on a storage battery circuit of about 110 volts by means of a voltmeter of known resistance. Resistances above a megohm could not be accurately measured, so when they occur they are

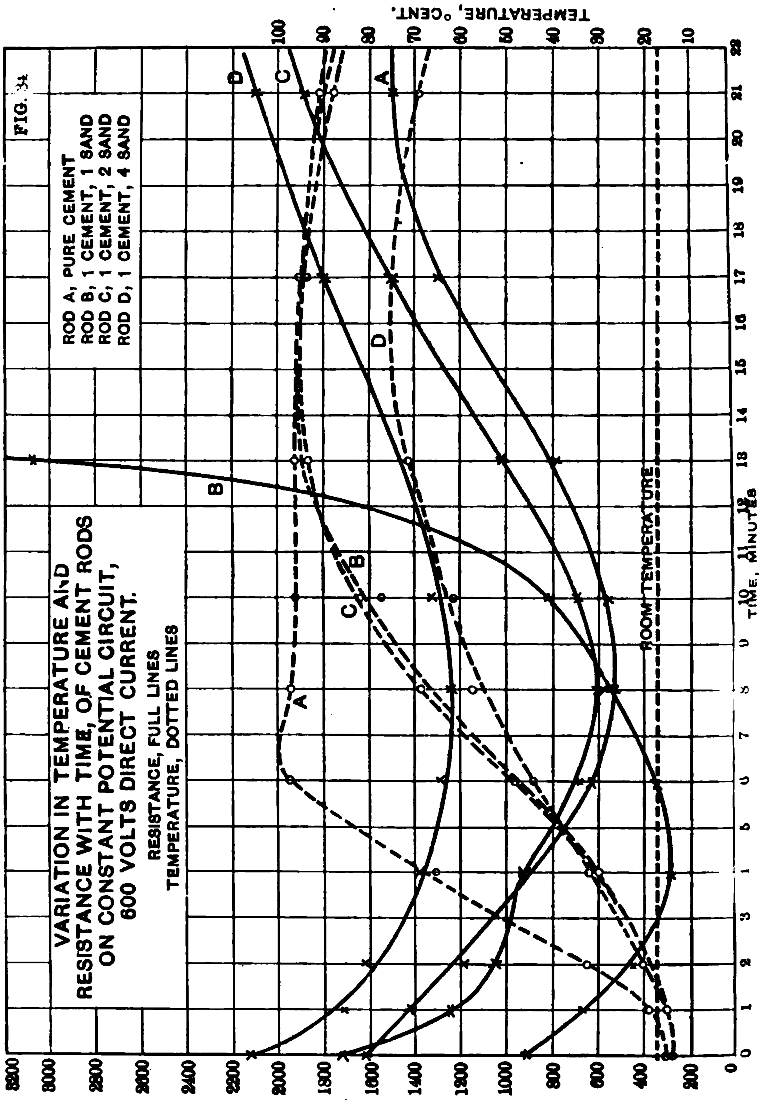


FIG. 34.—Application of power to cement resistors. These curves are of the early stages

simply indicated. Resistances were measured at intervals of a few days, the rods being kept in a moderately dry room.

The results are shown in Fig. 33, the resistance for ease in comparison being expressed as specific resistance, or resistance in ohms between opposite faces of a centimeter cube. These curves show a gradual increase in resistance with age; due apparently, mainly to drying out of moisture; but possibly in part to the chemical changes in setting. They also show a large increase in resistance with the addition of sand.

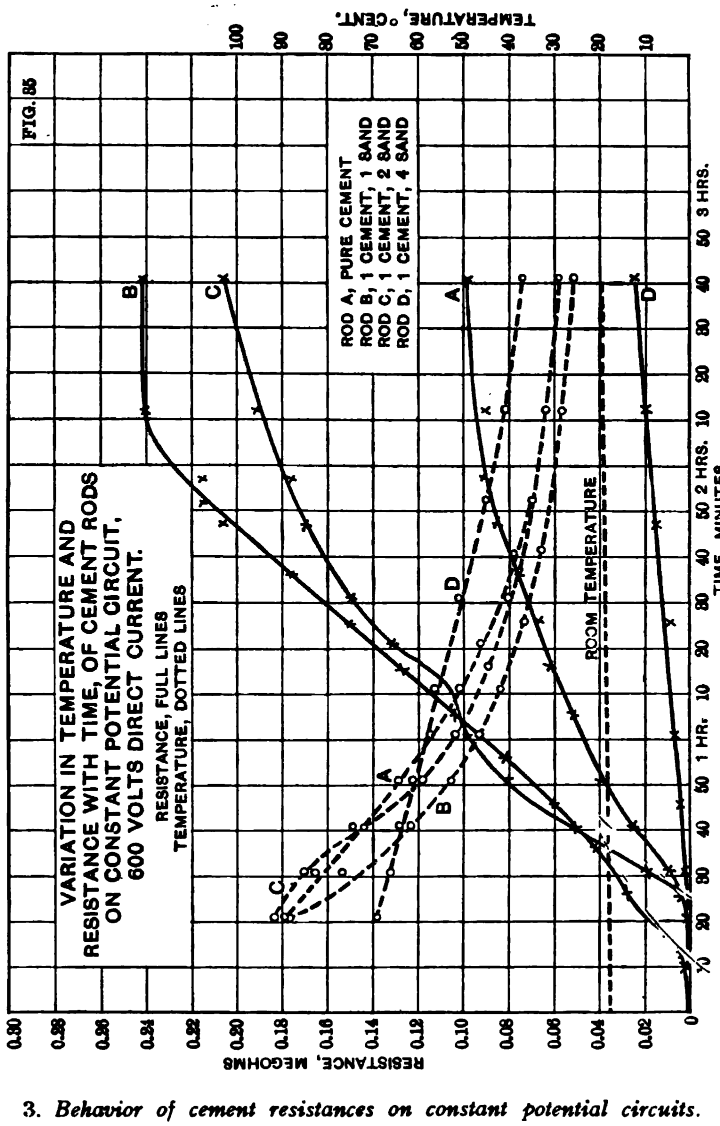


FIG. 35.—Application of power to cement resistors. These curves are the continuation of the previous curves to a smaller scale

3. *Behavior of cement resistances on constant potential circuits.* The tests on variation of resistance with age being concluded and all the rods being dry and well set, tests were next made to observe their action on a constant potential circuit. One rod from each of sets *A*, *B*, *C*, *D*, was

taken and soaked in water for sometime so as to insure uniform moisture conditions. After draining a few hours they were connected to a 600 volt direct-current circuit and readings taken of temperature and resistance at short intervals. The readings are plotted in the curves of Figs. 34 and 35. Fig. 35 is the continuance of Fig. 34 to a smaller scale of time and resistance. The resistances are those actually measured. The multipliers to reduce these to specific resistance are:

A multiply by 0.836
B " " 0.898
C " " 0.907
D " " 0.912

These curves show that the resistance at first falls rapidly, at the same time the temperature rising to nearly the boiling point. At this period a large amount of steam is given off. The resistance after reaching a minimum commences to rise. The temperature has a maximum occurring a few minutes after the minimum of resistance. After this the temperature continues to fall and the resistance to rise, both tending towards constant values.

It is interesting to note that rod *D* has the highest initial resistance and the lowest final resistance. The low maximum temperature attained, 75° cent. is the explanation of this, the initial resistance being so great that the rod could not heat up sufficiently to drive off its moisture in the time taken for the test. The initial resistance of *B* being lower than *A* is rather peculiar, in view of the curves obtained on drying out the rods, but is probably due to *B* having soaked up the water more thoroughly than *A*.

The amount of energy dissipated before the resistance has increased to a prohibitive extent is also of interest. If we consider three times the initial resistance as the permissible amount, then these rods gave the following results approximately.

	Time in minutes to reach three times initial resistance on 600-volt circuit	Kilowatt-hours absorbed and dissipated	Average kilowatts input
Rod *A*	28	0.0885	0.190
Rod *B*	13	0.0713	0.329
Rod *C*	26	0.0845	0.195
Rod *D*	56	0.1170	0.125

4. *Effect of moisture on resistance.* The tests already described indicate the importance of the moisture in the rods, but to further prove this point the following test was made. Two rods of each set, *A* to *E*, were taken. They were soaked in water for several days. When removed they were allowed to drain a few hours, and the resistance was then measured. They were next slowly heated over a bunsen burner for several

hours so as to drive out the moisture. After cooling the resistance was measured. They were again soaked in water as before and the resistance measured. The specific resistance in each case is given in the following table. Resistances over one megohm could not be accurately measured, so are simply indicated.

SPECIFIC RESISTANCE

	A No. 1	*A* No. 2	*B* No. 1	*B* No. 2	*C* No. 1	*C* No. 2	*D* No. 1	*D* No. 2	*E* No. 1	*E* No. 2
Wet before heating......	1078	1200	1552	1137	1930	1764	2240	1800	2910	3270
Dry after heating......	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus	1 meg plus
Wet after heating......	965	1270	1310	1483	2550	2810	2855	3490	6520	6420

This experiment agrees then with the others in showing that the conductivity is due to moisture.

5. *Conductivity at high temperature or pyro-conductivity.* Having shown that the resistance of cement increased enormously on heating sufficiently to drive out the moisture, the next point taken up was whether the resistance would again become lower on continuing to raise the temperature. For this a number of rods were made of pure Portland cement, 15/16 in. diameter and about 6 in. long. One of these rods was taken and provided with copper terminals placed 1 in. apart, each terminal being a sheet of strip copper ¾ in. wide, tightly clamped around the rod. Connections were made to a 116-volt storage battery so that the resistance could be determined by measuring the current in the rod and the voltage across it. The current was measured by a d'Arsonval galvanometer with adjustable shunt, and the voltage on a Weston voltmeter. Arrangements were made to heat the short length of rod between the terminals with a blast lamp. It was considered best to use as high a voltage as possible for measurement so as to render thermo electric effects negligible, preliminary tests having shown that these were very noticeable with low voltages. The following table gives a summary of the tests. The cement rods had been allowed two days to dry and set.

Variation of resistance of cement rod on heating.

Resistance megohms	Approximate temperature
0.144	Cold before heating.
54.500	
45.900	Slowly heating up
76.700	
8.970	Beginning to get red hot.
0.780	Red hot.
0.178	Partly white hot.
0.131	White hot.

These results are rather rough owing to the impossibility of heating the rod uniformly, and the absence of any means of obtaining the exact temperature, but they indicate the general principle that as the moisture is driven out the resistance increases enormously, but as red heat is approached, it falls rapidly, and at white heat is practically the same as when cold and moist. That this fall in resistance is due to temperature and not to a permanent chemical change is shown by the resistance returning to its high value when the rod cools.

The cement was rendered very weak and brittle by the heating, resembling a piece of chalk.

6. *Change from moisture conductivity to pyro-conductivity with high voltages.* The experiments of the previous section have shown that the conducting properties of cement depend upon three distinct states of the material. These are:

1. A condition of good conductivity depending in value upon the amount of moisture present. It is on this account liable to wide variation with time, and completely disappears when the temperature is raised to the boiling point of water.

2. A state of low conductivity, approaching that of a good insulator, when the cement is dry and its temperature below a red heat.

3. Another condition of good conductivity at and above a red heat; the resistance at this stage being nearly the same as in the first.

It was in accordance with these properties that in the test of section 3 the temperature of the resistance rods never rose above 100° cent., the period of high resistance being insurmountable by the moderate voltage employed.

To see if, with a higher voltage per unit length, the interval of practical insulation could be bridged, the following experiments were undertaken.

A number of pure portland cement rods were made ⅝ in. in diameter and about 6 in. long. Copper bands which could be clamped around these at any point were used as terminals.

The first experiments were made on 600 volts direct current, the terminals being set at various distances apart down to 0.25 in. Even with this small distance between terminals it was impossible to pass the insulation stage. There would be a violent production of steam for a few seconds, and then no further action. Frequently the rods would crack in two from the high steam pressure produced.

Experiments were next tried using a 25,000-volt, 60-cycle, testing transformer. On account of the small capacity of the generator supplying this, the current available was very small; also the regulation was poor causing a large drop in voltage under load. Tests were made with the terminals on the rods 4 in. apart. The voltage was adjusted to about 8,000 volts at no load. If the rod was quite damp when put on the circuit, the rush of current was usually so great as to open the circuit breaker. When slightly dryer a large current would flow for a short time, lowering the voltage very greatly; at the same time incandescent spots and streaks would form on the rod from which spectacular streams of flame would shoot out a foot or more, continue for a few seconds and then disappear. The voltage would then rise to its no-load value indicating a very high resistance. The experiment could be repeated by soaking the rod in water for a few minutes. But finally a rod was found coming within the capacity of the apparatus. The voltage being thrown on the incandescent streak spread from one terminal to the other, the rod gradually heating up all over. It ran quietly for about a minute, the voltage falling to 2000, and could probably have been kept at incandescence indefinitely had the power been available, but the apparatus beginning to heat, the current had to be cut off. After the rod had cooled, the application of 8000 volts produced no effect, showing that moisture is necessary to start the action. Probably the rods could in all cases have been heated to incandescence had the power been available.

These experiments at 600 and at 8000 volts show that the passing of the period of high resistance is not so much a question of average potential gradient, as of maximum potential available. It is reasonable to suppose that the material becomes conducting in spots, and that the high voltage will concentrate on any high resistance portions.

It is also important to notice that to start the action the initial moisture conductivity is essential.

7. *The properties of cement as a resistance when used in the form of concrete.* As in most cases when portland cement has been used for a resistance in practice it has been mixed with broken stone and sand to make concrete, some further tests were made with this material. The proportions by weight of the material were about as follows:

Edison portland cement	100
Sand	200
Broken limestone from ¾ in. down to powder	100
Broken limestone, 2 in	100
Water	65

This mixture was molded in wooden boxes to form blocks 10 in. by 9. in. by 7.75 in.

Variation of resistance with age. For this a column of six blocks was built up. The blocks were joined together with pure cement mortar, only enough being used to fill up the irregularities. Several strips of sheet iron were placed at the top and bottom for terminals, being bedded in cement mortar. The dimensions of the finished column were 48½ in. between terminals, and 10 in. by 9 in. in cross-section. The blocks being made at different times were from two to three weeks old, and having stood out doors and been soaked with water in setting up the column their condition was rather indefinite. The following table shows the resistance for the first six days after building the column.

Time after buildings, days	Resistance ohms	Specific resistance
0	920	4340
1	898	4230
3	1068	5030
5	1178	3560
6	1177	5555

As would be expected in such a large mass of concrete the change in resistance is very slow.

Behavior of concrete blocks on constant potential circuits. The circuit used for this test was a 2300-volt, 60-cycle lighting circuit. A single block was used, being set up so as to give a length of circuit of 7.75 in. and a cross-section of 10 in. by 9 in.; the terminals as before being strips of sheet iron.

The action in this case was exactly the same as in the test made with the small rods. The current was at first large but fell rapidly as the moisture boiled off, the rod becoming almost an insulator in a short time, Pouring water over it and allowing it to soak in would bring the resistance back more or less to its original value. The action took place so rapidly that it was very difficult to obtain good tests. The following figures will, however, give some idea.

In the first test made, the current started at about 15 amperes and fell in 23 minutes to .2 ampere.

In another test made some months later and when the block was quite dry, the current started at 2 amperes, reached a maximum of 4.4 amperes in 1 minute and fell to one ampere in 3½ minutes.

Summary and conclusions. The tests made with cement rods having different proportions of sand show a progressive increase in resistance with increase in the amount of sand, leading to the conclusion that the sand acts practically as an insulator distributed through the cement, so diminishing the effective cross-section of the rod.

All the experiments on the change in resistance with age or with heating indicate that at moderate temperatures the conductivity depends almost entirely on the amount of contained moisture. It would appear probable that the moisture dissolves a portion of the cement to form an electrolyte which being diffused through the body of the cement conducts the current, the solid part of the cement simply acting as a container for this electrolyte.

The studies of concrete while not as complete appear to agree with these conclusions.

The experiments on resistance at high temperatures and at high voltages show that cement possesses in addition to its low temperature or moisture conductivity a high temperature or pyro-conductivity. Also that a high voltage is able, in some manner to bridge the interval of high resistance and raise the material to incandescence.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 30, 1908.

TESTS WITH ARCING GROUNDS AND CONNECTIONS

BY ERNST J. BERG

It has long been known that when an arcing ground occurs in a system, abnormal voltages and consequent failure of apparatus often result. This series of tests was started with the hope of being able to deduce some mathematical expression which would represent these phenomena with reasonable accuracy. The mathematical expression did not materialize, but in view of the importance of the subject, and believing that the results will prove of some interest and value, I give them in the following paper. The theoretical explanation might form the subject of a future paper.

In the tests power was supplied from a three-phase turbo-generator operated at 25 cycles and 11,000 volts. During the tests this generator also furnished power for railway and other purposes, so that the load, and therefore the wave-shape, was not the same throughout. Some endeavor was, however, made to find whether the outside load affected the readings, but the results were not conclusive and rather negative. It seemed, therefore, that at least in a general way the impressed, or rather the generated wave-shape of electromotive force was of little importance.

The current was carried to the experimental station through a three-conductor cable 4000 ft. long. The diameter of each conductor was 0.365 in. and the resistance 0.31 ohms. The capacity between conductors was 0.27 mf. and between each conductor and the other two and ground 0.45 mf. Two sets of 110-kw., single-phase, core-type transformers of similar type were used; one to reduce the voltage from 11,000 to 370, the other to raise the voltage from 370 to 33,000, the voltage used in the experiments. The arcing grounds were established on the high potential side of the transformers.

Fig. 1 gives the principal dimensions of the step-up transformers; that is, the transformers at the terminals of which the experiments were made.

The low-potential winding was made in four coils, each of 24 turns. These coils were placed nearest the core. The connections of the coils are shown in Fig. 2. The inside coil on one leg was connected to the outside coil on the other, and all coils were connected in series for 370 volts. The high-potential winding was in 18 coils, nine of which were on each core. The two outside coils, *A*, Fig. 3, had a tap brought out from the middle of the winding, the other coils, *B*, had no taps. The two *A* coils had each 426 turns, the *B* coils 482, making 8552 turns in all. The coils were connected as shown in Fig. 3.

In the paper one-half of the *A* coils is referred to as "the end coil," which, therefore, have 213 turns, or one-half of the turns of the *A* coils. The normal voltage between them is 2.49% of the primary voltage.

Terminals were brought out from the taps indicated. The exciting current was 3% of the full-load current, the core loss 1.2%. Primary and secondary resistances were each 1% The total reactance was 3.5%. The capacity between the primary and secondary winding was 0.003 mf., and the capacity between primary and secondary and ground was approximately the same. In all experiments the transformer cases were grounded.

The arcing connections between terminals or to ground were made by approaching a small wire to the terminal. Unless stated to the contrary, the arcing connection may be assumed to have practically no resistance. As will be seen in one of the experiments, substantially the same results were obtained when a resistance of several thousand ohms was inserted in the ground circuit.

The striking distances were taken by means of needle gaps in series with which were resistances of such a value as to limit the current to about 0.5 amperes. It was found that this resistance could be varied over a wide range without affecting the results, but that the actual contacts in the spark-gap circuit must be carefully made, since if an arc was established in any of the connections local oscillations were set up and too high striking distances resulted. The striking distances given represent the highest values obtained after a whole series of tests. These high values were, however, quite consistent so that tests repeated different days would check within a few per cent.

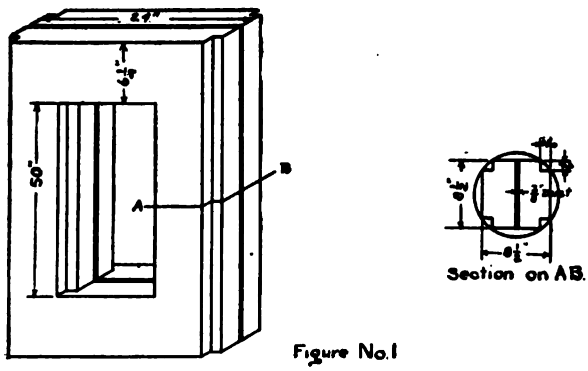


Figure No. 1

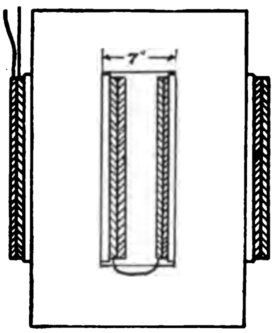


Figure No. 2.

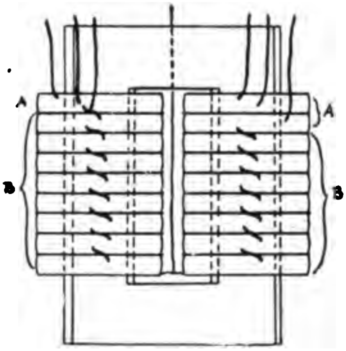


Figure No. 3

The normal striking distance between lines at 33,000 volts was 2 in. The striking distance across the first two taps—820 volts—was so low as to make the reading uncertain—it was less than 0.03 in.

In the first test which is shown diagrammatically in Fig. 4 one of the high-potential terminals of a 33,000-volt transformer was connected to one of the high-potential lines of another similar idle transformer through an arc. To introduce considerable capacity in the system, the other high potential line was grounded as was also the transformer iron. As the terminals *a* were brought within striking distance, a series of static sparks was established, which by their bluish-white color and snappy sound indicated a very high frequency.

Shunting the transformer was a spark gap, *b*, which at the time discharged over a 6-in. space; that is, three times the normal distance. A spark-gap, *c*, was placed across

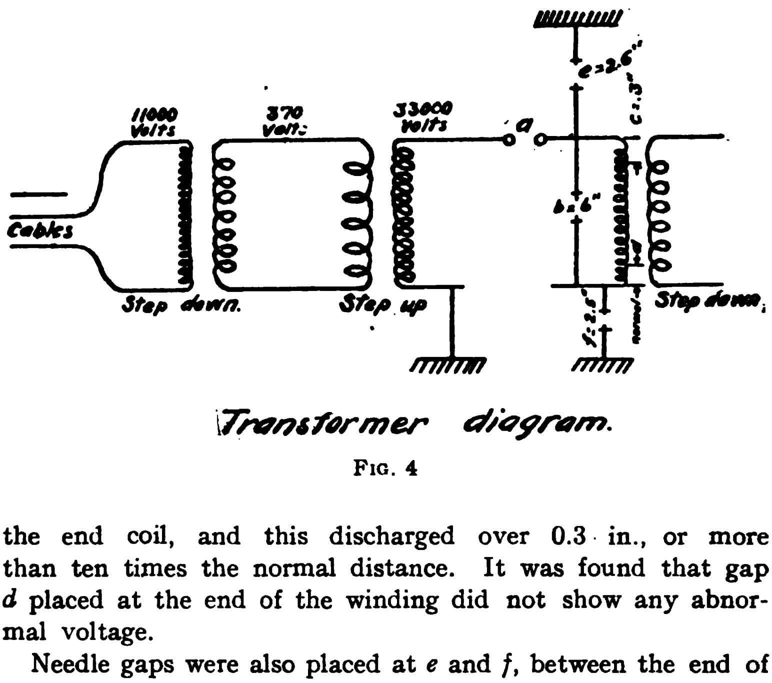


FIG. 4

the end coil, and this discharged over 0.3 in., or more than ten times the normal distance. It was found that gap *d* placed at the end of the winding did not show any abnormal voltage.

Needle gaps were also placed at *e* and *f*, between the end of the winding and ground, and these discharged over a distance of 2.5 in., showing that the winding was subjected to excessive voltage not only between turns, but also to ground.

In the second test, Fig. 5, the same general arrangement was used, but the ground connection of one of the lines of the step-up transformer was removed. Under this condition the spark at *a* was very faint, due to the slight charging current, and the voltages were very much reduced as seen in the figure, in which for convenience sake the striking distances are inserted directly instead of the spark gaps. These two experiments indicate what might take place when transformers are connected or disconnected by an air switch, or a switch which permits of some oscillations before the circuit is definitely made or opened.

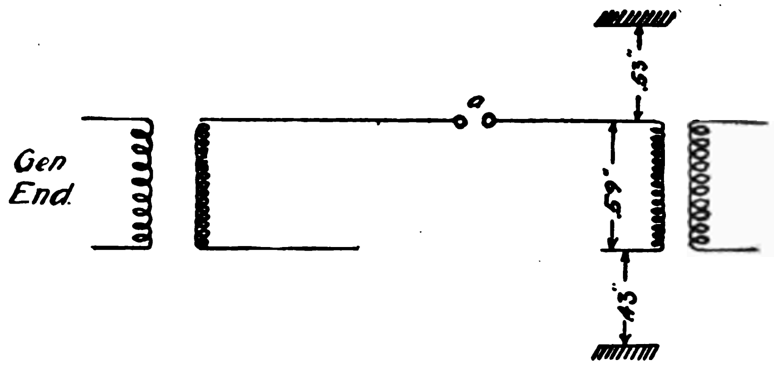


FIG. 5

In the third test an arcing ground was made at the terminal of the step-down transformer as shown in Fig. 6. With an arcing ground, the striking distance between the terminals and between one terminal and ground was 4.1 in. or more than double the normal value. Across the 2.5% tap nearest the

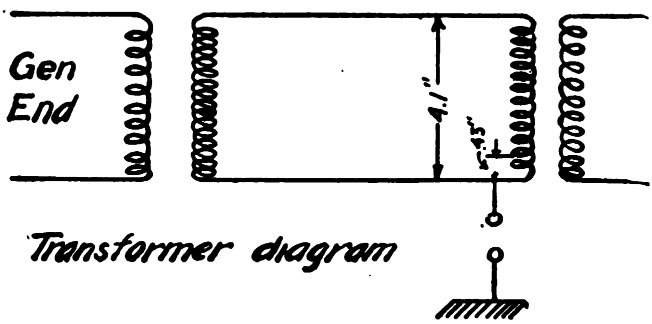


FIG. 6

arcing ground the striking distance was more than 15 times the normal, but no apparent abnormal voltage existed at the end coils on the ungrounded side of the transformers.

The fourth test was made with transformers connected three-phase. Three transformers with the primaries and secondaries connected delta were used to reduce the voltage from 11,000 to 370; three others, with the same connection, to raise the voltage from 370 to 33,000 volts. One of the high potential lines, or rather the junction of two transformer windings, since no transmission line existed, was grounded by an arc, as shown in Fig. 7.

The top diagrams indicate that delta-delta connection was used, and show the maximum striking distances across windings and across an end coil. The lower diagram is a scale drawing

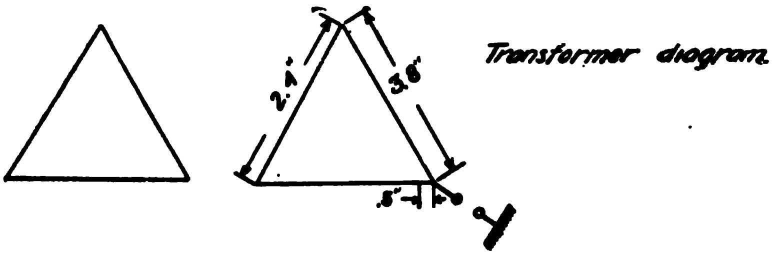
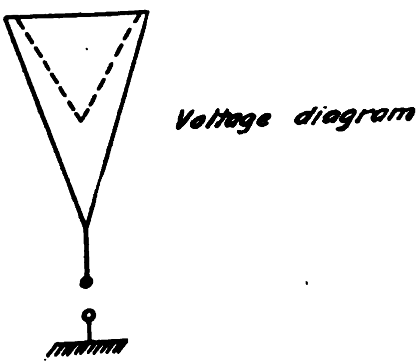


Fig. 7



to show the magnitude of the normal striking distance—in dotted lines—and those existing with the arcing ground.

It is interesting to note that the striking distance across the two transformers nearest the ground was 1.9 times the normal. The transformer opposite to ground was subjected to 1.2 times the normal voltage.

In the next two tests the step-down, as well as the step-up transformers, were connected open delta, or V. By referring to Figs. 8 and 9 it is seen that with this connection, particularly

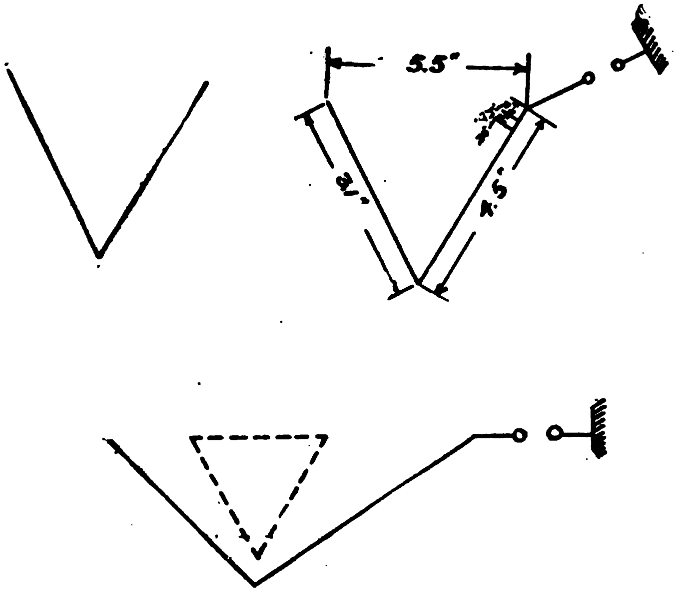


FIG. 8

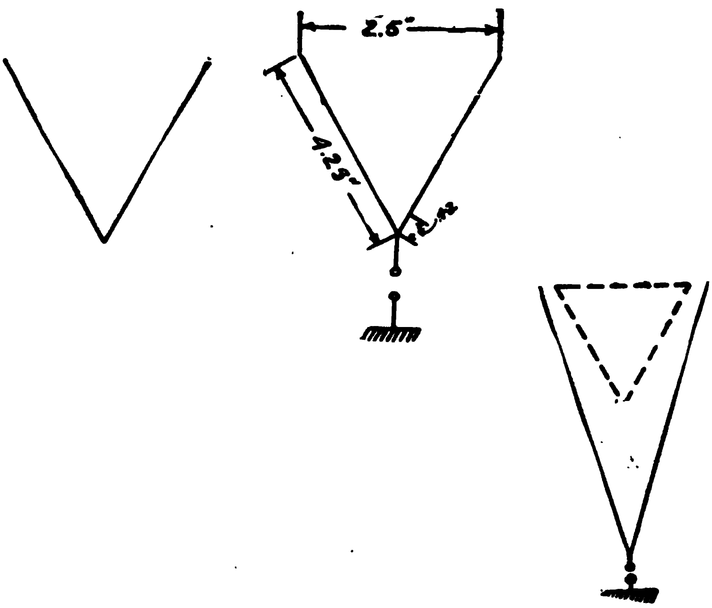


FIG. 9

when the arcing ground took place on one of the outside lines, the transformers were subjected to very high stresses. For instance, in the fifth experiment. Fig. 8, when an outside terminal was grounded, the striking distance between the other outside terminal and ground was 2.75 times the normal; across

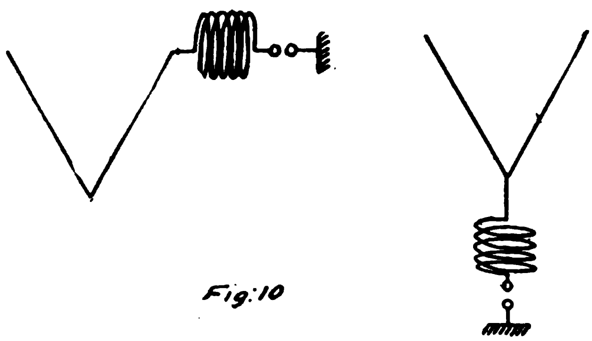
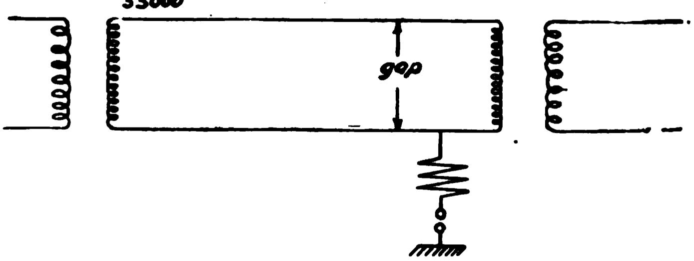


Fig. 10

one of the transformers it was 2.2 times, and across the other 1.55 times the normal value. The striking distance across the first 2.5% tap was 0.45 in., or about 15 times the normal, across the next tap 0.3 in., or ten times the normal.

In the sixth test, Fig. 9, the middle line was grounded and

Fig. 11.



Resistance	0	16000	160000	340000	1×10⁶	2×10⁶
Gap length	3.6"	3.6"	3.5"	2.6"	2.5"	1.75"

the striking distance across each transformer was 2.1 times the normal. In both experiments the striking distance across the end coil nearest the ground was from 15 to 20 times the normal, but no abnormal voltage was detected at the end turns opposite the grounded side.

In the seventh test a very wide range of inductance in the shape of air coils was inserted at the transformers, as shown in Fig. 10, and the ground made on the line side of the coils. These coils were of the same dimensions as the coils used in the transformer. It was found that the number of turns did not affect the results in any way that could be classified.

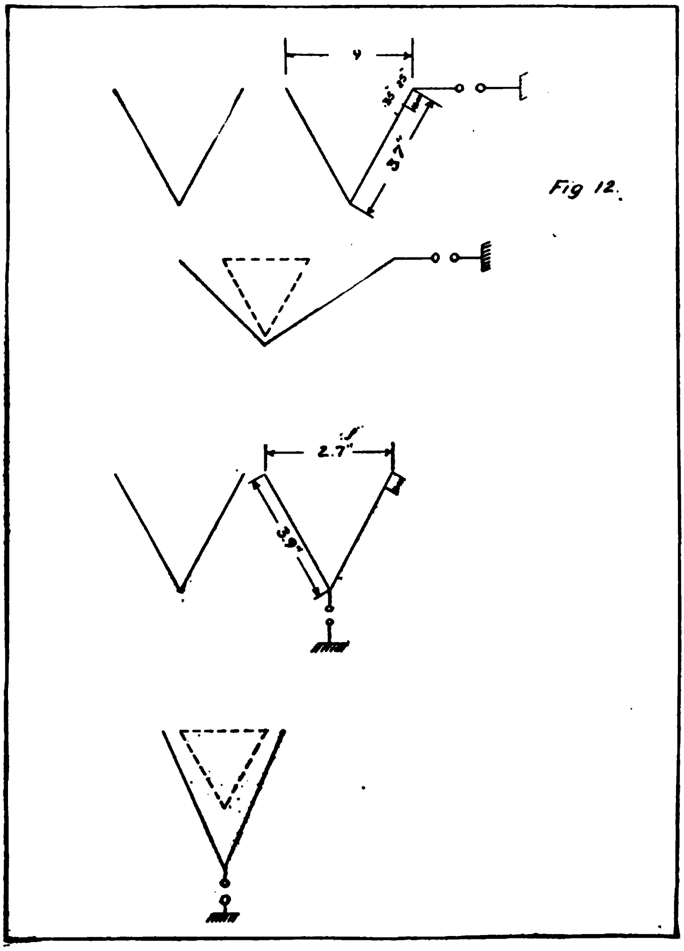


Fig 12.

At times a large reactance, say 20% of the transformer turns, would show lower striking distances, then suddenly perhaps the wave-shape slightly changed, or something else happened outside of the experiments, and the striking distances would be even greater than when no coils were used. The coils seemed to resonate with some of the higher harmonics; and since there is probably a large number of higher harmonics, each coil found one which suited the natural frequency of the transformer winding and the coil.

The eighth test recorded in Fig. 11, shows the effect of resistance in the circuit of the arcing ground. The diagram and the table explain themselves, and show in a general way that arcing grounds over insulators, through wood, etc., are practically as destructive as grounds without resistance.

Electrolytic cells in series with resistance

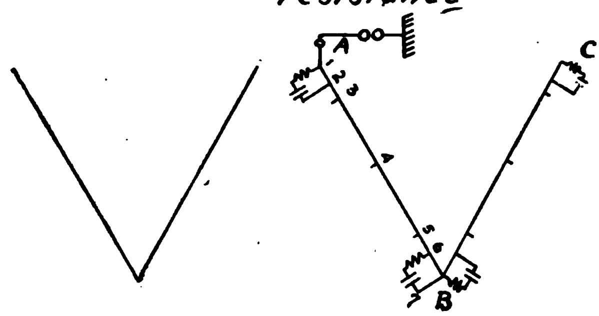


Fig. 13

Each cell consists of:-

175 Ohms.

Volts	AB	BC	AC	1-2	2-3	1-4	4-7
Gap	4 7/16	2 15/16	5 3/16	.045	.162	1 3/16	1 5/16

Various methods of relieving these strains, particularly the strains on the end turns, were tried.

For instance, in Fig. 12, which illustrates the open delta connection, the end coil was shunted by a resistance in series with a gap, the gap being so proportioned that a discharge would take place at abnormal voltage only. Various resistances were tried, but even the most favorable did not reduce the voltage entirely. By comparing Fig. 8 with Fig. 12, it is seen that the reduction in voltage across the first end turns was 50%, but the stress across the next coil was somewhat increased.

The voltages across the entire transformers were also decreased. It may be of interest to add here that this method of protection was quite effective at low voltages. This leads the writer to

Electrolytic cells in series with resistance

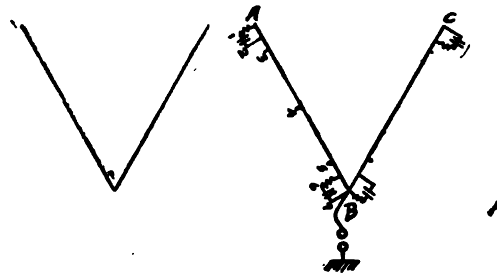


Fig. 14.

Arcing B

(Each cell consists of: —

1000 Ohms.

Volts	AB	BC	AC	6-7	5-6	4-7	1-4
Gap	3 1/4	3 5/16	2 13/32	.135	.250	1 1/4	1 5/16

500 Ohms

Volts	AB	BC	AC	6-7	5-6	4-7	1-4
Gap	2 11/16	3 1/2	2 9/16	.170	.305	1 5/16	1 1/16

175 Ohms.

Volts	AB	BC	AC	6-7	5-6	4-7	1-4
Gap	2 13/16	3 9/16	2 7/8	.151	.366	1 7/8	1 3/16

believe that with very high voltages when local oscillations of considerable energy are set up in the shunted circuit, this method will prove of relatively little value.

Ordinary tin foil, mica and electrolytic condensers shunting the end turns were very effective in relieving the strain in the shunted coil, but transferred it to the next section.

Resistances in series with a few cells of electrolytic condensers caused some improvement as is seen by comparing Figs. 13 and 14 with Fig. 8.

Loading the transformers experimented with did not materially affect the results.

Finally, tests were made where one line was grounded permanently instead of through an arc, and it was found that no abnormal voltages existed, the striking distances being those corresponding to the impressed voltage. This suggests the advisability of making a permanent ground on any line which by some accident has become grounded, the permanent ground to be removed after the fault has been remedied.

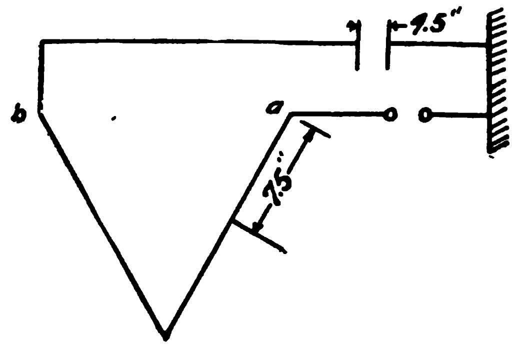


Fig. 15

Before closing it may be of interest to add an instance of the effect of an arcing short circuit which took place during one of the open-delta tests with the connections shown in the wiring diagram, Fig. 15.

Line *a* was grounded through an arc, line *b* connected to ground by an electrostatic voltmeter, having 4.5 in. distance between plates. As line *a* was grounded, an arc struck between the plates of the electrostatic voltmeter, resulting in a short-circuit on the transformers. At that time an arc struck from the terminal of line *a* to the terminal which was brought out from the middle of the winding, a distance of 7.5 in., or practically seven and a half times the normal striking distance. It is of course possible that the spark might have been still longer if the terminals had been further apart.

In conclusion it would seem as if with increasing line voltages it may be desirable to resort to some new methods of protecting the winding of transformers and other apparatus connected to the high-potential lines. One method might consist of a series of small electrolytic cells shunting the individual coils; by this arrangement these high-frequency surges would be transferred from each part of the tranformer to the lines. It seems unlikely that electrolytic cells shunting the lines but not connected to individual coils would entirely eliminate these internal disturbances, although with such cells there is no likelihood of the voltage across the entire transformer being materially increased.

Finally, it must be remembered that in these tests no high-potential transmission lines were used, and that, therefore, the results do not actually show what happens in a large system. From a few observations made in such systems the writer feels, however, that in general similar stresses result. Actual careful tests on such systems would prove of great value, bearing as they do on the choice of transformer connections.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 30, 1908.

CRITICAL STUDY OF LIGHTNING RECORDS ON TAYLOR'S FALLS TRANSMISSION LINE

(Papers by J. F. Vaughan and N. J. Neall*)

BY PERCY H. THOMAS

The following study of the Taylor's Falls line lightning data has been made for the purpose of discovering what inferences as to the nature of the attack of lightning on a transmission line can be safely and properly drawn from the unusually complete data recorded.

Interpretation of tell-tale papers. The correctness of all inferences presumably depends on a correct interpretation of the significance of the various types of punctures in the tell-tale papers; hence this matter was given special consideration. A careful study of the original papers shows the punctures in the tell-tale papers taken from the gaps in the ground connection of the insulator pins to be of three sorts.

1. Very fine, almost invisible punctures, usually occurring in large numbers and scattered round a central point or points. These are often so numerous that the paper is actually eaten away for a small space, giving a superficial appearance of the second type. This first type is characterized by a sharp edge, looking almost as though it had been scorched and usually by a few small punctures in its neighborhood.

2. Distinct individual holes, varying in size from that made by a small needle to large holes, all having the appearance of having been torn in the paper. These all have rough hairy edges but show no signs of burning.

3. Individual holes of the general character of the last but with burned or charred edges. This type may show any amount

*Presented at New York, May 19, 1908.

of burning from a slight scarring to the complete destruction of the paper.

In general these three types are clear and easily distinguished. They are clearly to be interpreted as follows:

First type. Puncture due to charging current taken by the pin in view of its static capacity to the line wire. This charging current evidently will exist under normal voltage conditions, if the width of the gap in the ground connection where the tell-tale is placed is sufficiently small to be broken down by the voltage normally existing. Trouble was experienced at first from the honeycombing of tell-tale papers during normal operation, since the ground gaps were set too small. The readjustment of these gaps is noticed in the large chart, Fig. 11, under date of June 10. When these gâps were finally set above the breaking limit of the normal voltage, punctures of the first type must have indicated abnormal voltages, and the size of the puncture indicated the amount of charging current taken by the pin or sometimes the number of times such voltages were repeated.

The *second type* above, indicated " spill-overs "; that is, the jumping of a static charge over the surface of the insulator. This was a very common occurrence in these experiments. Spill-overs are distinguished from the first type of puncture by their size. Only the finest punctures can be caused by the charging current to the pin itself, on account of its small static capacity. On the other hand, when the spark jumps from the line to the pin the static capacity of the line comes into play and also any charge coming to the line from the atmosphere and a much larger discharge results.

The *third type* is of the nature of the second, except that after the spill-over, current from the generator has followed.

The following analyses are based on the above interpretation of these paper punctures, which the writer has no doubt are substantially correct.

Analysis of storms. Storm of July 4. This storm is of special interest, since there happened to be no power on the line at the time the storm occurred. The direction of the storm is west to east, crossing the line two miles from Hugo at about pole 918. There are a number of relatively small punctured papers between the main centre of disturbance near pole 918 and the sub-station; those occurring beyond pole 1135, five miles from pole 918, appear to have been caused by the *first type* of sparking; that is, by charging current to the pin itself without discharge over the insulator. These punctures were made presumably before the taking off of the power from the line on the morning of July 4, or perhaps after it was put back before the papers were taken out on July 6. They may, however, have been made by waves of static from the disturbances occurring near the middle of the line. The first explanation, if true, means that these particular gaps were set so close as to show these fine punctures when there was no noticeable abnormal disturbance.

There seem to have been two distinct local disturbances in the neighborhood of pole 918. A heavy discharge must have struck at pole 918 on all wires and have traveled in both directions on all wires. The spill-overs tributory to this discharge on phase A appeared last at pole 928 in the direction of the sub-station, and at pole 906 in the other direction. On phase B spill-overs appeared last at pole 924 in the substation direction and at pole 909 in the other; on phase C there were small spill-overs to 909 (possibly to 894) and a large one at 924.

There must have been a second discharge near by, according to this analysis, centering at poles 931, 934, and 937. The spill-overs from this disturbance seem to have been confined to poles not distant from the center at pole 934 more than six or eight poles. And although three insulators were shattered near pole 934 there were apparently not more than four other spill-overs. It is possible that the very small spill-overs at poles 955, 958, and 961 were due to this same discharge. Their appearance indicates rather quiet static.

It so happened that this discharge, or these discharges, came on the section of line, a little over a half-mile long, between ground wire A and ground wire B. That this is the case seems certain, for the punctures of the papers are nowhere so large in the general region of that storm as around 918 and 934. It is unfortunate that the storm did not actually strike over one of the sections protected by grounded wire, as this would have given more valuable evidence as to the protective effect of such wires than now exists.

As a matter of fact nearly all of the tell-tale papers in the *ground connections* of the overhead ground wire B discharged enough electricity to show a hole perhaps one-half as large as the largest punctures in the tell-tale papers in the insulator pin-ground wires on the unprotected portion of the lines. These overhead ground punctures, further, grew smaller in size from the end nearest the maximum disturbance to the other end. They are quite as likely to have been caused by the static wave passing down the transmission line from the region of pole 918 as by the direct effect of the disturbance on the overhead ground wires. They may, of course, conceivably be due to a suddenly released bound charge, but they seem to be much too large for this. The evidence against the "bound charge" hypothesis is summarized in the second paragraph below. Two insulators were shattered under this overhead protection, one only one pole within, the other four poles within. This shattering probably had little to do with the effectiveness or lack of effectiveness of the ground wires, since the disturbance arose on an unprotected portion. The grounded wires on the other side of the unprotected portion of the line showed very much smaller punctures in their ground connections and only three in all located next to the end of the section.

The smaller of the two main disturbances, near pole 934, which was the one nearer the last described section of ground wire (type A) was central about seven poles away, while the greater disturbance near pole 918 was central about five poles from ground wire B section. No very satisfactory conclusions can be here drawn as to the protective power of the overhead ground wires, since the storm did not strike so as to give them a trial. It may, however, be safely concluded from the tell-tale papers that the ground wires are very active and pass much current. This is almost certain to be helpful. The other types of overhead ground wires located at distances from one to six miles, seem to have taken no discharge of any particular significance.

It is very important to note the nature of the discharges in the tell-tale papers of the lightning rods that are entirely separate from the line structure. In the case of nearly every lightning rod on the whole system small punctures were observed, usually much less than the size of a normal spill-over puncture on the line, but very numerous. In one case, not near the centre of disturbance by two miles, pole 820, what would be taken as a very severe spill-over puncture if found in the insulator tell-tales, was observed. This must have meant a severe direct stroke. In none of these cases of spill-over size discharges in the lightning rods was there any sign of disturbance on the adjacent portion of the line. From these observations on lightning rods it may be concluded that the disturbances on the line are in all probability due, at least in their severe form, to direct charges from the air and not to the accumulation and release of bound charges on the line. The latter could not occur on the rods; and if the rod discharges come directly from the air, it is evident that the line charges as well do so in the main, since both sorts seem of the same nature and of the same general magnitude. Furthermore, the heavy discharge at the lightning rod near pole 820 should have produced a severe discharge on the line, if the sudden release theory be the right one, for the conditions must have been particularly favorable at this time.

During this very active storm there were only very few discharge indications on the station arresters. At the power-house there were very small discharges on all three legs of the horn arrester. At the sub-station there were discharges, both series and shunt, in leg C on the low equivalent and a discharge in leg A on the electrolytic. This is very significant, for the storm was severe and prolonged in the center of the line and yet was hardly noticeable at the station arresters; in other words, the disturbances did not travel to the station without a considerable loss of energy.

Storm of August 18. This storm followed the direction of the line from sub-station toward power-house pretty closely and caused apparently five principle disturbances. The storm first made itself felt at or about pole 1387, where it caused spill-overs on all three line wires in the immediate neighborhood, especially on A and B. Here it very possibly started a short-circuit on the system through wire B on pole 1387 and probably through either leg A of the low equivalent or the horn arrester at the power house or leg A of the electrolytic arrester at the sub-station. This, then, may be taken as the cause of the dip in voltage referred to in the notes of this storm. Then nearly a mile farther on another discharge of great severity occurred at or about pole 1357. This destroyed several insulators and probably caused another short-circuit through wire C on pole 1341 and through leg A on one of the above arresters or perhaps more than one. This shut down the power house as reported and for the rest of the storm there was no power on the line. There are no more evidences of burning of papers.

Poles 1342 to 1385 had the ground connections removed from the pins and can show the actual discharges only by the shattered insulators and the split poles. Heavy spill-overs occurred on wires A and C on the pole having grounded pins nearest to the disturbance at pole 1351 and spill-overs were continued for nine poles on wire A. Spill-overs on other wires seemed to stop at pole 1341. Two or three spill-overs occurred in the next third of a mile on wire C, the last one on pole 1314, being one of the most severe of the storm. This spill-over was probably due to a separate disturbance.

No more very serious spill-overs occurred, though there was a single one of some violence at pole 909 wire A, four poles under the overhead ground wires, type B. This is significant, since there is no discharge of any importance at all in the neighborhood outside of the ground wire section. A single very severe spill-over occurred at pole 563 on phase C. No other spill-over occurred near it.

Overhead ground wires B were active, since at nearly every grounded pole a hole occurs in the overhead ground tell-tale papers of the size of a large spill-over puncture. There does not seem to have been any other evidences of a discharge in this neighborhood except that at each end of the ground wire section a line spill-over occurs on one wire, though these are different wires, and both are within the overhead grounded wire section. This looks suspicious, as the line spill-overs either cease on the line wires or at least become very much smaller exactly at the ends of and outside of the ground wire sections. There is apparently no evidence to show what is the phenomenon causing this particular condition.

The series coil tell-tale papers in this storm are very significant. The choke-coils at pole 1356, within one pole of shattered insulators on both sides on one wire and very close on all wires, had all three papers burned up, showing a very violent discharge in shunt to the coils, enough to ignite the papers. The papers for the coils on wires A and B at pole 1230 were burned up, this pole being a distance of two and a half to three miles from the nearest disturbance. There is a small puncture in the series coil in wire A at pole 1615, five miles in the other direction from the nearest discharge of any apparent severity. As these coils have only twenty turns of conductor of one foot diameter, probably not equal in inductance to more than a hundred yards of line wire, a very sharp wave-front is shown by these series coil discharges.

The above storms have been taken as samples. The analyses of the others have been made similarly, but the results can be best studied by topics.

Protective power of overhead ground wires. In making inferences on this subject, the most important one of all in some ways, it is necessary to use the greatest caution not to be misled. The data are not as full as was to be hoped but are nevertheless better than any definite data obtainable elsewhere.

Ground wire A. This section was subject to some disturbance, more or less, in five storms. There was one spill-over on an insulator in this protected section due undoubtedly to a disturbance outside the section, and four punctures in tell-tales of equivalent size in the grounds from the overhead wires, all in the storm of July 4. In only one instance was there any violent disturbance in the immediate neighborhood of these ground wires, viz., July 4. This occurred just outside the protected section. The overhead wires did not seem to have much effect. This was not of the most approved form and not much was to be expected of it.

Ground wire B. In case of this section there were fifteen spill-overs of all sizes over insulators under the ground wires and twelve more or less equivalent punctures in the ground connection of the overhead wires. There were six storms in which records are furnished, but only two in which punctures of spill-over magnitude occurred. In one case the centre of discharge was just outside of the grounded section and in the other was directly over it and did not extend outside. In the former case two insulators were shattered, one located one pole inside the protected section, the other four poles inside. This probably had little to do with the effectiveness or lack of effectiveness of the overhead ground wire. In the latter case, where the line showed spill-overs and the attack was in the grounded portion, the discharges seemed to occur near the two ends mainly as though there had been two independent discharges. The protective power does not seem to have been particularly effective here.

Overhead ground C. Records on this section are given for six storms, none however showing any discharges of any serious amount near this section. In only one case was there a noticeable discharge in any ground connection from the overhead ground wire. There was, however, no spill-over on the line wires on this section. This type of overhead ground is not a good one and in no case seems to have exercised much if any protecting power, nor to have had an opportunity to exercise any.

Ground wire D. This section is reported in six storms, two line spill-overs are shown on same pole, and nine more or less prominent discharges in the ground connection of the overhead wires, none being larger than 0.1 in. and most being smaller. No severe storms appeared to have attacked this section of the line. However, the two spill-overs were fairly severe and occurred six poles from the end of the section. The middle pole is eleven miles from the ends.

While the overhead ground sections as shown in the records are very active in discharging current, it is doubtful whether any of them would be wholly effective, as installed, in protecting the line wires from every severe discharge, such as occurred a number of times on this plant. It seems probable that the line wires would share the most severe discharges that attack the ground wires; the danger is that the latter are neither well enough spaced from the line wires nor often enough grounded completely to protect the line wires.

Lightning rods. There were six spill-overs on the line on the section protected by type A lightning rods on pole tops in five storms, and four more or less severe punctures in lightning rod papers. In the storm of August 4 and 6 there was one severe discharge in which there were three insulators shattered on this section and some very severe spill-overs but the lightning rod papers seem to have been omitted or destroyed, except a few at the end away from the disturbance. A very severe discharge occurred at pole 1028 three poles from the lightning rods, but no noticeable discharge occurred in the ground connections. The line, however, was evidently not protected. Although the rods will undoubtedly take such discharges as come to them, they probably cannot be relied upon to protect the line wires and insulators. They will undoubtedly, except in very extreme cases, however, protect the poles from injury.

Lightning rods B. These rods showed minor activity in all or nearly all storms, and greater activity in the three August storms which were centered within five miles or less of this section. This activity consisted in a multiplicity of very fine punctures aggregating a good size hole in the case of some ten or twelve rods. In addition on July 4, there was a violent discharge showing what would be considered one of the most violent spill-overs in an insulator pin ground. The center of the July storm was over two miles away, but some smaller disturbances evidently occurred nearer to this special arrester discharge.

Lightning rods C and D. These showed very much the same phenomena as the other types: activity with small punctures, many per paper—in about one-fourth of the rods—nothing on many of the intermediate poles. The active poles were pretty evenly distributed. There were no disruptive punctures of magnitude in the lightning-rod grounds. There were, however, no disturbances in the immediate neighborhood of these rods.

Line choke-coils. Choke-coils were located at poles 986, 1203, 1356, 1615. The storm of August 18 was severe at pole 1356 and moderately severe at poles 800 to 900. The tell-tale papers at pole 1356 were all burned up, these at pole 1203 three miles away were burned up in wires A and B, and a fair-size explosive puncture occurred at pole 1615, five miles away. Three good size punctures occurred also in the coils at pole 986 in wires B and C about two miles from the nearest disturbances.

This appears to show that charges of some magnitude pass along the line or possibly that their effect is increased by oscillation. It must be remembered that a ground on the line, lasting for even a very small fraction of a second, will cause the full static charge of the line on the one side of the choke-coil to pass by to earth, not merely a charge received from the air. Also that a burned paper is quite likely to be merely ignited by a spark of some violence, when it may be subsequently consumed by natural causes. This action is known to have actually occurred.

Effectiveness of Arresters.

Storm of June 25, not severe. A relatively small but sharp discharge occurred at pole 1571, four and a half miles from the sub-station. Small static discharges occurred on one leg in the sub-station low-equivalent arresters in both series and shunt gaps and on one leg in the series gaps only. On the electrolytic at the sub-station, discharges occurred in all three legs, and two showed the following of a small quantity of generator current. The discharge on the line caused spill-overs on all three wires at the same pole. The low equivalents at the power house did not discharge.

Storm of June 29, not severe. This storm showed no spill-overs except the shattering of two insulators at poles 1474 and 1478 causing a short-circuit. There was no evidence of a discharge on the low-equivalent arresters at the sub-station, seven miles away, nor on the electrolytics at the same place.

The plant was shut down by this experience. There were no arrester discharges at the power house.

Storm of June 30, *not severe.* In this storm which attacked the line four miles out from the power house, all legs of the power-house low-equivalent arresters discharged, showing signs of dynamic current in the series gaps, but only a good static puncture in the shunts. The power-house horn arresters discharged only in leg B, but showed a heavy burning in the tell-tale paper of the resistance shunt ground connection, and a smaller burning of the paper in the main ground. These discharges of this storm out on the line were relatively severe and eight insulators were shattered, distributed on all three wires. No injury was done to station apparatus. On legs A and C the only arrester to discharge was the low equivalent. Furthermore, on line wire C there were two heavy spill-overs only a mile from the station, and two more spill-overs a little farther off. The sub-station arresters showed no signs of discharge. In all probability there was no discharge on the line within some 35 miles of the sub-station.

Storm of July 4, *severe, no power on line.* Although this storm, which has been already analyzed, was very severe, no great disturbance was manifested at the stations. The disturbance was centered at the middle of the line about 20 miles from each end. At the power-house the horn arrester discharged in all phases and the low equivalent probably in leg C, series and shunt, and the electrolytics at the sub-station in leg A. The discharges in the horns were small while those in the others were relatively large. The low equivalents at the sub-station discharged faintly in leg C. This is an interesting case, showing that the very severe discharges do not necessarily carry with power for half the length of the line. The nearest real spill-over to the sub-station seems to have been at pole 1135, 14 or 15 miles away though a number of quiet static punctures in papers occurred around poles 1500 to 1600. The nearest spill-over to the power-house was the main disturbance over twenty miles away.

Storm of July 13 *and* 14, *not severe.* A sharp stroke occurred at about a mile and a half from the power house, shattering two insulators on wire B and causing a number of spill-overs on wire C. At a point three miles from the power-house on wire A, there was an uncertain sort of burning in tell-tale which may have been a severe spill-over but probably was not.

At the sub-station the horn arrester discharged in all legs. The electrolytic showed a heavy dynamic burn in leg A, and static in leg C. The low equivalents showed nothing. At the power house the low equivalents showed small burns in legs A and B, and the horn in B, with static in A and C.

Storm of July 19, *distant from line.* There was considerable quiet static near the center of the line and many of the lightning rods showed small punctures, as did the overhead ground wires. There were however no spill-overs and no arrester discharges on either end of the line. This storm was said to be distant. Some of the punctures in the lightning rods are given as over 0.04 in. in diameter. They must have been caused by repeated discharges of very small magnitude.

Storm of August 1, *distant from line.* This storm was similar to the last storm except that the lightning was distant to the west instead of to the east. There were no spill-overs and no activity in the lightning rods nor in the overhead grounds. None of the arresters discharged.

Storm of August 4 *and* 6, *severe, parallel to line.* This storm was very severe at a point about 14 miles from the sub-station, and showed almost no activity at any other point, except that through the central portion activity was evident but in no very great violence. There are one or two doubtful spill-overs recorded nearer the sub-station. Except for a good clear static puncture in the ground connection of the power house horn on leg C, there was no discharge at the power house. At the sub-station, on the other hand, there were discharges in all legs of the horn arrester; in legs A and B, small in volume but perhaps as large as the 5,000 ohms series resistance will permit, and very numerous; and the tell-tale paper was nearly burned up in leg C. The electrolytic at the sub-station showed static in leg A, a small amount of burning in leg B, and also a second static discharge, and no discharge in leg C. The low equivalent at the sub-station showed a discharge of fair size in leg C, but no burning. The Hugo arrester showed discharges in the first gap in all legs, and in legs A in addition a heavier discharge in the next gap which has a less series resistance. The Hugo arrester is only three-quarters of a mile from the nearest severe discharge, occurring on leg A, which is the leg on which the discharge in the second arrester gap at Hugo occurred. This case is a good example of how quickly the energy of a traveling wave can lose its intensity.

Storm of August 8 *and* 15, *severe, parallel to line.* This storm passed from the sub-station up the line but was not severe. There were a few scattered spill-overs but no broken insulators. One heavy discharge occurred on leg *C* at pole 1434, about 7 miles from the sub-station. At the sub-station the horn arrester discharged in all legs and held dynamic current in leg *C*. The only other indication of holding of current on any other leg is at the power house in leg *A* in the horn. Discharges occurred in all legs in the Hugo arresters and in one case in all three gaps. This suggests that the test on the arrester is more severe when there is no spill-over; this seems reasonable, for the line then has no relief at the point of attack. At the power house the horn discharged in all three legs and held a little in legs *A* and *C*. The low equivalents discharged in the power house in leg *C* and held the arc a little in the series gaps; static only appeared in the shunt. The electrolytic discharged at the sub-station in leg *B*.

Storm of August 18, *very severe—parallel to line.* This storm passed up the line just as did the previous one and had a severe spill-over at a point about 10 miles from the sub-station and another at about 19 or 20 miles and a small one at 12 miles from the power house. At the sub-station the horn arrester discharged in all legs, the electrolytic in legs *A* and *B*, and the low equivalent in leg *C*, series and shunt. The electrolytic seemed to hold a little generator current. The Hugo arrester discharged in all phases in the first gap and in the third gap on legs *A* and *B*. At the power house discharges occurred in all legs in the horns and the low equivalent.

Storm of September 6, *not severe.* No spill-overs occurred on the line except two or three near the center. There were numerous quiet static puncturings throughout the length of the line. The only arrester activities were at the sub-station where quiet disturbances occurred in legs *A* and *B* on the horns, in leg *C* on the electrolytic, and leg *A* on the low equivalent. The storm was to the east of the sub-station and not directly on the line.

The remaining storms can be briefly summarized. On the *16th of September* a storm crossed the line at the power house and caused two shutdowns. All legs of all power-house arresters discharged in all gaps, and there was one spill-over on wire *C* near the power house, within a few poles of the end of the line. The horn showed hold-over current in all legs, the low equivalent in only leg, *B*, and not much there. At the sub-station discharges occurred in the horns in legs *A* and *B*, and in the electrolytics in legs *B* and *C*. There was one discharge in each leg at Hugo.

On September 18, spill-overs occurred on all wires about six or seven miles from the sub-station. Discharges occurred in the sub-station horns in all legs, and in the electrolytics in legs *B* and *C*. No other discharges on the system.

On September 19, a storm 11 or 12 miles from the power house caused a discharge in all three phases in the horns in both stations and in phase *C* at the Hugo arrester. No other discharge occurred.

General. An examination of tell-tale papers shows that the sub-station horn with 5,000 ohms resistance in series showed only very fine punctures, showing great limiting of discharge. The horns at the power house having about 500 to 600 ohms of series resistance, and all the low-equivalent arresters, showed considerably larger punctures indicating a freer discharge, while the electrolytic would probably show a still larger puncture except for the fact that the charging current to the arrester itself, which usually follows the discharge for a few moments, burns the paper and enlarges the static punctures, so that it is nearly impossible to determine the size of the hole made by the static. Of course, a holding of the generator current will mask the static punctures; this often happened with the horn arresters as well.

It seems highly probable from the data as to the discharges of arresters that the sort of disturbance making the heaviest demand on the station arrester is the stroke on the line which is nearly but not quite sufficient to cause a spill-over. This disturbance may send a wave the length of the line sufficient to cause arresters to discharge, but not severe enough to be more than the arresters (in this case at least) could handle. These waves go far but they are not enormously severe. This is an important conclusion. The cases in which a much more severe attack on the line causes a spill-over does not send as severe a wave to the station apparatus as the latter type. This is natural as the spark once established to ground will readily discharge most of the severity of the disturbance which would not have been able to get to ground without the actual establishment of a ground arc. Exception is here made of course to the direct stroke of great severity at the station which still remains the most dangerous of all lightning attacks. It is interesting to note that the storm of September 16, occurred at the power house and that no damage was done to apparatus, though the arresters showed vigorous action in all gaps. This could not have been a very severe disturbance.

The arresters seldom if ever, during this season seem to have been put to the limit of their ability to care for the discharges. In no single instance on any one leg did all the sub-station arresters of various kinds discharge at the same time in all gaps. The Hugo arrester discharged in all three gaps only once and then in only one phase. At the power house, omitting the storm of September 16, which occurred at the power house itself, there were only three cases where all the available gaps on any leg discharged, and in one of these cases the severity of some of the discharges was not the maximum. This is important, and is part of the evidence tending to show that the waves coming in to the station (omitting again the direct stroke at the station itself) are not of enormously great volume or energy or voltage and can be properly handled by non-arcing arresters, even of the series resistance type. This conclusion is of the greatest importance, and seems very well substantiated by the data of this paper. Of course, the insulation of this line is not as high as can now be obtained through the newly developed insulators on the very high voltage lines, so that more severe waves must be expected to appear at the stations in some of the systems now building, but the principle is the same and additional insulation strength can if necessary be given to station apparatus and circuits.

From this line of reasoning; namely, that the limit of discharge capacity of the arresters was not reached, it may be concluded that the so-called sensitiveness of discharge, at least as between the arresters installed in this plant, is of relatively no moment. Since the arresters have been able easily to care for all discharges, and since they have discharged often but rarely if ever to their limit of capacity, any greater sensitiveness would add nothing. In fact the less sensitive the arresters the better, as long as protection is secured. A certain risk is run every time that an arrester discharges, and they should act only when necessary to protect the line. The quality most requisite is the freedom of discharge. Furthermore, any degree of sensitiveness may be obtained by the proper setting of the initial gap and any arrester can be set as sensitively as necessary, provided only that it still remains non-arcing.

The following is a summary of the relative action of the various arresters during this season:

At the sub-station	Discharges.
Horns without low equivalent or electrolytic........	12
" " " "	21
" " electrolytic......................	15
Low equivalent with electrolytic...............	2
" " without "	6
Electrolytic " low equivalent.............	12

It thus becomes evident that the horn arrester is here set to be the more sensitive and always responds, and that if either one of the others starts it prevents a discharge in the third. It must be noted that no direct discharge on to the line occurred near the sub-station.

At the power-house.	Discharges.
Horn without low equivalent...................	7
" with " "	10
Low equivalent without horn..................	2 { before resetting.

The same conclusion follows here as from the sub-station data. It is probable that the horn arrester when using series resistance is not a free discharge but that either of the other types were, since they would seldom discharge together.

As to non-arcing power, it may be said that the horn with resistance and the other types were non-arcing on this plant which has a relatively limited power behind it, but that the horn without resistance was not non-arcing. This is as expect d, and is shown by the numerous records of the opening of the circuit breakers.

Shattering of insulators. This is a most important and instructive study. Out of forty-two injured insulators only three were punctured. The others were shattered, that is, had their petticoats cracked or broken without any direct puncture of the porcelain. The cause of this phenomenon, at least in the case of these results, must be taken to be the shock of the static and not at all the effect of the generator arc, as is frequently supposed, for in the storm of July 4 there was no power on the line and eight insulators were shattered. This shattering sometimes does and sometimes does not cause a shutdown. This direct shattering of insulators without puncturing by the lightning is startling and undoubtedly indicates that the discharge is very abrupt and violent, it further indicates the difficulty of testing insulators for actual service conditions by laboratory apparatus. In addition to the 39 shattered insulators there were nearly 150 spill-overs that did not cause injury to the insulators. Inspection of tell-tale papers shows that these spill-overs were often just as severe in many cases when no injury was done the insulator as in the other cases. Although the data in the paper do not enable a conclusion to be definitely drawn, it seems true that many of these spill-overs occurred without shutting down the plant.

From the general appearances of the disturbances it seems a fair inference that, while the number of spill-overs was undoubtedly increased by the presence of the ground wires to the pins, there would have been many such discharges in any case. This view is supported by the breaking of insulators in the storm of August 18, when there were six insulators shattered in a section of line where the ground connections had been removed. A most important result follows from such a premise. If the discharges that are to be expected are irresistable and are going to ground in any case, then the great cost and mechanical complication that is proposed for many high voltage plants may fail to serve the purpose expected. And also a second most important conclusion—which is nothing but common sense and has already been sometimes recognized—every insulator should be so constituted as, when subjected to an irresistible potential, always to fail by discharge over its surface and without cracking, for then often little or no inconvenience or delay will result, while if the insulator is broken or punctured, an interruption and long delay for repairs may result. This point cannot be too much emphasized. This ideal condition seems to have been pretty well realized at the Taylor's Falls plant as far as freedom from insulator puncture is concerned. If each spill-over had been a puncture it is easy to see what a serious menace it would have been.

Character of individual discharges. A careful examination of the distribution of punctures and spill-overs indicates with considerable certainty that a given disturbance attacks the line at a very definite point and may either go over or through an insulator to ground, or if unable to do this to pass along the line to find a weaker spot or to wear itself out. It is certain that such a discharge, at least in this plant, will pass by at least three to six ungrounded poles to go to ground over a pole with a grounded pin. These pin grounds occur every third pole. This means that the front of the static wave does not drop as much in potential along the line for three poles as the difference in the insulation strength between the grounded and the ungrounded poles. On the other hand, the wave will not pass by, perhaps ten poles, to discharge over one of the grounded pin poles. This indicates that the drop of potential in the wave front is greater in the ten poles than the difference in pole insulation strengths. The latter data come from the storm of August, 18 where six insulators on ungrounded poles were shattered within less than ten poles of grounded pins. In other words, not more than a thousand or at most a few thousand feet of the wave front will have travelled by an insulator before the maximum or at least the spill-over point is reached. This steep wave front corresponds to a very high frequency. It is well to notice in this connection that the feature that is of importance is the steepness and magnitude of the wave front of the initial discharge and not the frequency in the usual sense as is generally assumed In rapidly decreasing oscillations such as characterize static discharges, if a break-down does not come at the first wave it is not likely to come at all. There can be no proper frequency unless there are several complete cycles established and the formulas for steady alternating currents do not apply even momentarily for the initial wave front.

Damage due to a given storm is not usually limited to a few poles, it is limited but may often extend over a mile or two of line. This indicates that in a given stress locality there are a number of more or less individual discharges due to the same general conditions yet separate in space and perhaps a little in time. This conception seems very reasonable.

It appears to the writer that the spill-overs that have been here considered are largely due to direct strokes, major or minor, actually reaching the line wires. Not necessarily all of great magnitude, such as the strokes that are visible for miles, but large enough perhaps for discharging a relatively small area or volume of air, even only a few hundred feet in extent. This seems almost an inevitable conclusion from the Taylor's Falls data since the lightning rods several times showed tell-tale punctures in the ground connections exactly similar to the punctures in the pin tell-tale papers. These lightning rod punctures could not be due to released bound charges as the static capacity of the rods is too small. It is further hard to conceive of such concentrated discharges as are shown being due to induction from a distant cloud. Again it is difficult to see how enough energy can be stored in a short length of line wire such as seem to take part in most of these disturbances to do the damage that is manifest in the actual case. For these reasons and for others the writer considers these data strongly to confirm his previous opinion that disturbances of the general nature of these shown here, which are almost universal in transmission lines, are due to direct discharges of electricity at high potential out of the atmosphere onto the line wire.

A careful study of all the tell-tale papers in relation to their phase relation and their position on the poles shows that in a large majority of cases of isolated single spill-overs, the top insulator is not the one affected. The fact is marked when the total number of the specific instances recorded are considered. This has a most important significance, for it can indicate only that the charges approach from the side before the actual discharge rather than from the top, straight downward. On consideration this seems to be the natural course, for although any gradually approaching source of disturbance will tend to come downward gradually, yet at storm times there are always strong currents of air along the ground which would certainly overbalance any downward motion. Downwardly moving air can have no place to go without passing to the side after reaching the earth, so that it is extremely probably that the course of the air will always be along the ground with a slightly upward or downward motion. This means that the chances are that the side wires as well as the top wire will sometimes be reached by a discharge. Of course, this does not mean that the top wire will never be struck nor that the same exact phenomena will be found everywhere else as in this case, but in such matters as the locating of ground wires this possibility must be clearly borne in mind.

Furthermore, in some eight or ten cases of the most severe discharges the same pole shows spill-overs on all line wires, one of which (usually a side wire) is generally much lighter than the other two. This suggests the probability that, after such a very severe discharge has jumped onto one or two of the line wires, their potentials are so raised that they cannot contain the discharge and it jumps to the third wire. This will be of course on account of the impedance in the ground path. This does not seem perhaps a remarkable conclusion but it leads to an important inference, namely, that if overhead ground wires are to protect they must be so far spaced from the line wires as to prevent a discharge thereto. It is evident that the power of these overhead ground wires to carry a discharge to ground and prevent its jumping to a line wire will depend on the nearness of its ground connection to the point of attack. With such discharges as have been found in this case, which are undoubtedly typical of most plants, a ground connection more than a few poles away would be entirely inadequate. It is not so necessary that this ground be a perfect one, as to some extent any local rise of potential at the ground connection at the foot of a pole would tend to protect the line wires on the same pole.

Origin of lightning. Before summarizing the above discussion, it will be interesting to speculate a little about the nature of the phenomena in the clouds from which these disturbing actions come. According to a recent hypothesis, the rise of potential in the clouds is as follows: by some cause, perhaps the action of the sun's rays, there is produced a more or less gradual ionization of the air in certain strata of the atmosphere some distance above the earth. This produces electrons, (or negative charges) and positive ions, (which are loose atoms of matter with a positive charge). At the same time there is usually an accumulation of water vapor in the locality. It is known by laboratory experiment that at a certain pressure, water vapor will condense on electrons. Whenever the necessary pressure of water vapor is reached undoubtedly such a condensation will occur and these electrons, being loaded down each with a drop of water, will fall to the earth or toward the earth, leaving the positively charged ions suspended in the air. This will, of course, raise the potential of the positive charge, the energy for which process comes from the potential energy of the water drop, which it possesses in virtue of its elevation and its attraction by gravity. As this action goes on, there is produced a higher and higher potential of positive electricity built up by the step-by-step withdrawal of the electrons by weight of the condensed water vapor It may also be assumed that the water vapor goes on increasing in pressure in the upper region until finally, at a much higher pressure than before, the vapor begins to condense on the positive ions and they also then come down gradually.

Now as the two charged layers of air, positive and negative, will usually be widely separated by the wind and other agencies, there will exist throughout the region, charged bodies of air or mist which are some positive and some negative, the negative getting to the earth first or being carried to some other point, while the positive electricity (the usual polarity of the clouds) remains.

When, however, any two of these highly charged bodies of air of opposite sign come into the same neighborhood, there will be a discharge between them, if their potentials are high enough. This will be the well-known lightning in the clouds. Or if a positively charged region does not find an opportunity to discharge to a negative region in the air, it will gradually approach the earth and then discharge to ground.

Suppose that at the end of a hot day a highly charged layer of relatively cold and heavy air has accumulated above a warmer uncharged layer below, which has been heated by contact with the earth in the sunlight, much as a layer of oil may be made to support a layer of water above it, momentarily. The equilibrium is evidently unstable and the layers will overturn at any opportunity. When this process starts the cool air will break through the lower layer of hot air and the whole cold body of air, which is heavily charged electrically, will come to the earth at some point while the hotter uncharged air will move to one side and upward to make way for it. This action suggests the cold breeze which so often accompanies a lightning storm. In this case, of course, all the charge of the air will be discharged into the earth at or near the point at which it breaks through the warm layer either in a few heavy strokes, or, more likely, in a few heavy ones and a great many smaller ones, ranging all the way in size down to brush discharges to earth or accumulations of charge on a line, where there is not enough power to make a direct discharge.

Now this hypothesis accounts very nicely for the tentative assumption that a number of relatively severe flashes occur in one immediate neighborhood, practically simultaneously but not identical and not in exactly the same position. There is a large bulk of air to discharge and each discharge relieves only its own immediate region which is accessible to its discharge path. Other regions in the neighborhood may have no discharges at all, for the cold or charged air has come down only at a relatively few places. There would presumably be other more or less distant locations where the upper cold air layer would break through again and repeat the phenomena.

It is interesting to note that the effect of these ions on the air where a discharge is imminent, especially in the upper air, is greatly to reduce the jumping voltage of the intervening distance. This is the well-known action by which one arc will start another, and indeed is the process by which the arc itself is maintained when once started. It is the presence of the ions and electrons in the arc path, which allows the normal voltage to maintain an arc which may be so much longer than the distance that normal voltage will jump in the first place. If it be assumed that the number of ions in the upper air be considerable, this may mean that the jumping distance through the air in the region may not be so very much greater than the arc-holding distance. This would go far toward making the great length of many lightning strokes seem reasonable, especially in view of the generally accepted hypothesis that the long discharges are progressive, that is, made up of a great many shorter ones, following in quick succession. All the above discussion is purely speculative, but it helps to give a concrete idea of actions that are regularly observed.

Summary. The net result of these various considerations may now be summarized. The Taylor's Falls system as here reported was disturbed from time to time in particular localities along the line by lightning. In each such locality, the extent of which rarely extended over more than a mile or two, there were usually several more or less severe discharges which struck the line wires from the atmosphere. These charges when relatively mild charged up the line and sent waves of static in both directions along the line without spilling over. These waves though of diminishing volume were able to pass many miles and still cause arresters to discharge at the stations. These waves, however, were entirely within the power of the standard arresters at the stations to discharge to earth. This must inevitably be the case since the wave energy has to be carried along the line and by the capacity of the wires and the insulation strength of the insulators.

When the discharges striking the line are too severe for the insulators to withhold, however, they pass over or through the insulator to earth. This may or may not cause a shutdown, a fractured insulator, or an injured pole. In the great majority of cases here reported none of these resulted, unless it may be that shutdowns were frequently brought about. The data are not quite complete on this point. In going to earth these discharges will choose a path to earth not more than a few poles from the point at which they reach the line. They will exert a preference for the weakest of the two or three nearest poles, provided the difference in insulation strength is great, but they will not go much farther for a ground, probably even for a dead ground.

Also in this case in which spill-overs occur, waves of static are sent in both directions along the line but in view of the discharge to ground at the starting point these waves are very likely to be of less intensity than the waves produced by discharges into the line not quite severe enough to cause a spill-over. Thus a mile or two from one of even the severe strokes on the line the effect on the system is not especially severe.

The abruptness of the wave front of these discharges is of the order perhaps of that of a periodical oscillation of 100,000 per second, though it may vary through wide limits. Extra severe discharges when they come are almost sure to reach all three line wires at the same point, though it seems entirely probably that, at least in this plant, the discharges from the air do not strike directly downward but come in from one side or another.

In this district the discharges striking the line were sometimes very severe, so severe that they jumped freely to earth over insulators, cross-arms and poles, and with such static shock as to crack off petticoats in the absence of generator current.

Little protection is obtained from lightning rods located beside the line. Whether protection will be obtained from overhead grounded wires or not depends entirely on the arrangement of wires, the frequency of grounding, etc. Station arresters of the best types should, in the absence of severe discharges close to the station, protect adequately the station apparatus if properly insulated.

Horn arresters as here installed with some paths to ground without adequate series resistance, are not non-arcing and can be relied upon occasionally to shut down the plant. On the other hand, both the electrolytic and the low-equivalent arresters showed themselves properly non-arcing and caused no trouble on this score. The size of punctures in tell-tale papers produced by the discharge of one of the *waves of static* after passing along the line in the worse case does not exceed a very few hundredths of an inch in diameter, while the disturbances striking the line directly caused enormously greater punctures in the pin grounds, sometimes measuring an inch or more.

The above conclusions apply strictly only to this line and to this particular season, but it is evident that the nature of the phenomena must be essentially the same in most cases; and by making a common sense allowance for different conditions and different numerical values of voltage, insulation strength, capacity, etc., the present results can be applied to almost any high tension line.

In the operation of any high-tension system, it should be a strict rule to record and analyze all important breakdowns, use tell-tale papers and other recording devices where practicable, and to require reports of observed conditions and otherwise to arrive at the actual nature of the disturbances at the particular plant. This method of procedure though irksome, especially at first and if not systemized, will go far in the long run toward obtaining the most satisfactory operation. The educational effect on all persons concerned is in itself very valuable. Further, it forms a basis for future review of the situation should that become advisable.

Discussion on "Measurements of Lightning, Aluminum Lightning-Arresters, Earth Resistances, Cement Resistances, and Kindred Tests", "Tests with Arcing Grounds and Connections", "Critical Study of Lightning Records on Taylor's Falls Transmission Line." Atlantic City, N. J., June 30, 1908

J. F. Vaughan (by letter): It is gratifying to have a careful, independent analysis of the Taylor's Falls lightning records such as Mr. Thomas has given in his paper, and interesting to see wherein his conclusions differ from those of the original papers on this subject.

The main idea suggested by Mr. Thomas' paper, that the more pronounced disturbances at least have been due to some form of direct discharge between clouds and line, is fundamental, and requires radical modification of present conceptions of the nature of the direct stroke. It suggests that such a stroke may be:

(1) Of length varying from a few feet upward.

(2) Of quantity and intensity varying from a relatively small disturbance to a destructive bolt.

(3)* Of such a nature as to distribute itself with considerable uniformity over sections of line and overhead ground wires.

(4) Of frequent occurrence, amounting to hundreds of strokes during the season.

The main objection to the "Release of bound charge" theory is that the capacity of the line is not sufficient to account for the volume of discharge indicated by the tell-tale records. However, the potentials and rates of discharge may be sufficiently high to compensate for the relatively small capacity. There is little evidence of any great amount of energy in the discharges, even in the shattering of insulators, providing a high enough rate of discharge is assumed.

There is, however, ample evidence of extremely high velocity of disturbances in the rapid damping out of potential in the line, the mechanical nature of the insulator fractures, the activity of line choke-coils and the splitting apart of the laminations of the tell-tale papers.

In the discussion of overhead ground wires, Forms A and B, the records of storms of July 4 and August 18 are not considered as showing definite protective power. By reference to the original curves (Fig. 12 of the writer's paper) the record of the storm of July 4 shows by the activity of overhead ground wires A and B that the latter were well within the active area of the storm. If the curves representing line-insulator stress and overhead ground-wire discharge are added together, this fact will be evident. The curves for the ground-wire sections on each side of the storm center show that as the center is approached the activity of the sections increases rapidly, with no correspond-

* See original paper by J. F. Vaughan, Fig. 12, curves of July 4.

ing increase of stress in the line insulators until the unprotected section of line between the shielded sections is approached within a few hundred feet; that is, the shielding effect of the wires appears to be pronounced even to within a few hundred feet of their ends. The storm of August 18, which was reported as the most severe for years, was active over ground wire B. Although the discharge from the ground wire was considerably larger than in any of the other storms, the average disturbance in the line shielded by this construction is shown by the curves to be low compared with those of unprotected sections in other storms. Over the central portion of this section of the line there is only one heavy spill-over, and as that is within less than 1000 feet from the end of the ground wire it may have come in from the adjacent unprotected section.

Mr. Thomas calls attention to the probability that the side transmission wire toward the direction from which the wind blows is probably subject to more disturbance than the other wires. This exposure is shown in the general graphic chart by greater activity in the wire toward the approaching storm, excepting where the storm is overhead and near enough to cause spill-overs and physical damage, in which case the top wire seems to be the one most subject to trouble.

In interpreting the curves the following should be borne in mind:

(1) That the lower ranges of the scales of ordinates adopted for plotting the curves are exaggerated in order to show the smaller values more plainly.

(2) That the discharge paths of the shielding-device grounds are freer than those of the line, and the discharges being consequently less disruptive, are probably quantitatively greater than the line discharges for given sizes of puncture.

(3) That the sections of shielding wire are not long enough to insure the damping out of charges coming in from adjacent unprotected sections within the length of each shielded section.

In connection with the direct-stroke theory it is interesting to note that no clouds have been observed sufficiently low and close to the line to account for short direct strokes. Nor have any spill-overs been actually seen. Close watch is being kept on the line this summer to get information on the appearance of clouds and line during spill-overs, and the nature of insulator breaks is being further studied.

Charles P. Steinmetz: While some years ago the problem of electrical-power transmission and distribution, in its stationary condition, was already very well developed in most of its features, there always remained this class of phenomena, of which lightning is characteristic, which we may call transient phenomena; that is, phenomena which last only a short time, frequently an extremely short time, but which are of such a character that the damage they may do makes up entirely for their short duration.

We are approaching a clearer understanding of these phenomena and also a control of them, so that it looks not improbable that in a very short time lightning, and all these disturbances in transmission lines and transfoımers, will have lost their danger to us; that we will be as familiar with them as with the design of an alternator or of a motor, and that we shall be able to predetermine, control and eliminate them.

I am particularly glad myself to be able to see how the consensus of opinion of those engineers who are studying the subject most deeply is coming around to what I have maintained so many years, that the most effective protection of the transmission line is through overhead grounded wires. Some years ago, very few people agreed with that statement, now we find that most of them agree with it, and even these few doubting Thomases will, I hope, be convinced.

I believe to protect an electric system efficiently and effectively it is necessary to protect the line and protect the stations. We cannot expect to escape damage, no matter how complete the protection we install in the station, if we leave the transmission line unprotected. Neither is the protection of the line alone sufficient; but what I believe we can already, at this time, state in with fair certainty is that if the transmission line is well protected by overhead ground wires, whatever disturbances we get will not be so severe that we can not take care of them safely by protective devices in the station.

I do not quite agree with Mr. Thomas in explaining the disturbance in the Taylor's Falls transmission by direct strokes; or rather, to explain it more fully, I do not see an essential difference between a direct stroke, as described there, and the phenomenon of the bound charge of lightning.

Let us see what happens in a direct stroke. If the potential difference between the line and cloud rises so high that somewhere in the field the potential gradient exceeds the breakdown strength of air, a breakdown occurs, as a discharge from line to cloud, or into space, thus equalizing the potential. In the other case, if by a discharge in the clouds the potential difference between the clouds and ground is suddenly changed, the bound charge of the line is set free, and that means that suddenly upon the line a very high electrostatic potential is impressed which discharges from the line into space, if the voltage is beyond the disruptive strength of the surrounding space. In either case—whether this potential difference is created by a discharge into the cloud, setting free the bound charge, or whether it is created by potential difference between the cloud and ground—if the voltage is high enough, the discharge passes from the line into space, toward the cloud. I thus do not see how we can distinguish the phenomena of the bound charge from the phenomena of the direct stroke, but believe these two phenomena are practically the same.

There is only one point I want to mention, and that is to express my regret that in the tests and investigations valuable records have been lost by the combustion of tell-tale papers. These tell-tale papers can be protected by fireproofing, and I bring that to your attention, because it can easily be done (and it is very desirable to do it) by treating these papers with a solution of sodium tungstate (also called sodium wolframate). They become fireproof by such a treatment, and there is no longer danger of losing them or setting fire to them. A quarter of a pound of the sodium tungstate bought at any wholesale drug house, is dissolved in a pint of hot water, and the tell-tale papers immersed in that solution, and then dried. There is no apparent change, except that the paper is slightly rougher. You can write on it the same as before, the lightning discharge makes the same markings, the same punctures appear in the tell-tale paper, but it cannot be set on fire, the flame cannot consume it, and therefore you cannot lose any of the papers by fire. I believe it is very desirable to carry out this precaution. I do not know that there is anything else to add, and I thank you very much for the opportunity of expressing my opinion on these papers which have been presented.

P. M. Lincoln: I agree with Mr. Steinmetz that the most important question raised by the lightning-arrester papers is that of the ground wire, and I will take issue with Mr. Thomas in his interpretation of Mr. Vaughan's results which were presented to the Institute at the last meeting. In my own interpretation of Mr. Vaughan's results, I found to my satisfaction that there was a very marked protection given to the line at Taylor's Falls by the presence of the overhead ground wire.

Possibly I have not given this matter quite such close attention as Mr. Thomas has, but I would like to have him detail, if he will, the reasons why, and how he can draw conclusions to the contrary.

I would like to ask Mr. Creighton, too, whether or not the records obtained by him in Figs. 3, 4, and 5 were obtained with current on the line, or whether the line was dead at that time. I presume there was no power current on the line at the time the records were taken, judging by their shape. I would also like to ask Professor Creighton for his opinion as to the efficacy of the overhead ground wire.

A. E. Kennelly: Overhead wire protection is a matter of very great importance on account of the radical nature of the construction which it involves. This matter is one concerning which experience of some kind has been gained for more than fifty years; that is to say, ever since overhead wires have been put up for telegraph purposes there has been the same trouble with lightning, differing only from the trouble that transmission engineers have had, in the fact that the poles were ordinarily not so high as at present, that the insulators were very much weaker electrically, and that instead of having a high-potential dynamo at the end of the circuit, there was no appreciable power on the circuit. Nevertheless, the damage done by lightning was recognized at a very early date. Apparatus was burned out, insulators were destroyed, poles were smashed or damaged.

It was found that the lower wires largely escaped. I think that is the consensus of telegraph engineering opinion all over the world. The upper wires bear the brunt of the damage. Poles were found to be saved in very large measure by putting grounded wires on the poles themselves, putting a lightning protector on each pole. The upper wires were not grounded every half mile, as is customary with protecting wires; but nevertheless the protection from overlying wires grounded at distant stations was found to be material, although incomplete.

In my opinion we shall never have any system of absolute and complete protection against lightning, even with the best devices that we can install in the station, or the most perfect system of overhead grounded wires that we can devise. We can hope with care to minimize the damage due to lightning, but we shall always have some trouble left. Anyone who looks for a panacea against lightning is entertaining a very courageous expectation, which is likely to meet with some discouragement.

I think that we ought not to attempt to form too definite a conclusion as to the source of lightning disturbances upon the wire. Mr. Thomas intimates that the disturbances are mainly due to little direct strokes, but others think, from the same records, or with the same data before them, that the disturbances are due to the release of bound charges; while still others think they are due to inductive disturbances. There are so many possible causes for disturbances that we should hold our minds open and not consider that everything is due to one and the same source of injury. For example, in the case of an overhead wire, we all know that there is a movement of electrified air over the wires conveying electrical charge to them continuously. Secondly, we have the release of bound charges, and thirdly direct strokes. Fourthly we have a source not generally recognized, namely, electromagnetic waves. If over a distance of several miles there can be produced in a wireless telegraph antenna a received e.m.f. of fifty or one hundred volts from a small alternator at the generating station, surely a lightning discharge with its enormous generating power is able to produce electromagnetic-wave disturbances in long wires of very much greater magnitude.

It seems, therefore, that we should not try to formulate a rule and declare that all disturbances due to lightning in overhead transmission wires have one and the same origin. We must expect, with a number of disturbances, that a number of different kinds of apparatus may be necessary to be installed, some to protect against one kind of disturbance and others to protect against other kinds of disturbance.

John B. Taylor: Professor Creighton has shown his ingenuity in devising special pieces of apparatus to determine what is actually going on in a transmission line. We wish to know what we have to guard against, and I think that papers of this sort are more to be desired than many we have had in the past. The conditions of operation are so variable that some conclusions drawn as to the better of two types of arresters are not justified; but when we know what we have to deal with, and to a certain extent can duplicate the conditions in the laboratory, we can begin to produce apparatus which will meet the requirements.

I have not had a chance to give this paper as critical reading as I would like, but there is much confusion in my mind over the use of the term " lightning." I do not know why the word lightning should be applied in a new sense. The word has been in use for many years, and almost everybody in the profession, and out of it, has a pretty definite idea of what the term signifies. Professor Creighton, apparently, wants to call anything abnormal on a transmission line " lightning." When he speaks of the natural frequency of lightning, does he mean the natural frequency of the lightning stroke from the clouds, or the natural frequency of the discharge of the line, with which he is experimenting, to ground? The records show mainly frequencies of three thousand cycles, or in that neighborhood, and as I read the tests, this frequency is merely the one at which the particular line discharges to ground, and gives no indication of the frequency of the lightning discharge itself. The variation between 3,000 or 4,000 and 15,000 may be due to the distances out on the line at which the lightning discharge proper occurred. I trust he can give us a little defense of this use of the terms, because to my mind it has made a good deal of misunderstanding in reading the paper.

Reference is made to a further analysis showing in addition to 3,000 cycles or thereabouts, superposed higher oscillations of a million cycles. I believe he used the term lightning as applied to these million cycles. How can a lightning stroke a mile or more in length be expected to oscillate with a frequency of a million cycles? A stroke a mile long, with a period of oscillation of one million cycles, would mean a velocity of at least one million miles per second, whereas the known velocity of light and electrical impulses in the ether is only approximately 190,000 miles per second. Does the apparatus demonstrate this high frequency in the lightning stroke, or is it the period of parts of the test line and apparatus—a secondary effect of the lightning?

The data given on actual resistances of ground connections are valuable. The putting in of these ground connections goes largely as a matter of chance, and more perhaps as a matter of faith. We put up an expensive equipment of lightning arresters—and then run some kind of a wire into the earth, and seldom make tests to determine whether the latter is effective or not.

From one test, a value of 30 to 40 ohms is given as the actual resistance of the ground itself between two points several miles apart. I think there must be some mistake in this, as judging from a test made in dry rocky soil, the resistance of the earth, apart from that at and near the contact plates, is not likely to be anywhere nearly so high. Was this measurement made with alternating or direct current?

Mr. Berg gives us figures from tests of practical value, because the arcing ground unfortunately occurs at times on transmission systems. Mr. Berg does not offer any explanations as to the cause of this excess potential, and possibly in discussion he may give us his idea of it.

What appears to be the simplest explanation of this excess potential, as evidenced by the needle gaps, is a compensator or auto-transformer action in the transformer itself. The windings of the transformer have electrostatic capacity to ground, which capacity is not evenly distributed along the winding, but is greater in some parts than in others, giving an arrangement equivalent to condensers connected between points of the winding and ground. Considering one of these condensers near the terminal where the arcing ground is to take place, this condenser will become charged to a high potential, and as soon as the gap to ground breaks down, the charge will pass through a small portion of the transformer winding, stepping up the voltage at the other terminal of the transformer. Where two transformers are interconnected in an open-delta arrangement, the normal potential of one transformer is added to this excess potential derived through compensator action in the other transformer. This might explain why one line terminal in the open-delta arrangement shows higher voltage to ground, by needle gap, than the other line terminal.

In practice, of course, the action is not as simple as this, on account of the complex nature of the distributed capacity, reactance of winding, losses in iron core, etc., but this explanation of the phenomenon seems to be a simple, rational one.

One word more on Mr. Thomas's paper. I want to take issue with him on his choice of terms. I cannot understand why the term "static" is used here to represent anything but a static condition. In the old days we had "static" electricity and "dynamic" or "galvanic" or "voltaic" electricity, and the study of static electricity had to deal with the distribution of charges on bodies of different shapes, the forces of the attraction and repulsion between bodies when they were charged, and similar matters. The term "static" applies to a condition of rest. Now we seem to use the term to call to mind anything but a condition of rest. The term has crept into this use in the last few years and I hope we can find some other word which will more truly represent the condition of affairs, and not upset a term which already has a well-recognized use in the older books.

R. H. Marriott: In the territory in which Mr. Creighton was making his tests there were several wireless-telegraph stations from 1905 to 1907. At these stations we had a great deal of trouble with what is called "static." There were four stations: one at Pueblo, one at Altman, one at Colorado Springs, and one at Denver. At the Denver station were two masts 200 ft. high and 300 ft. apart, with a station house half-way between. One aerial consisted of a flat-top loop in the same plane with the masts, and stretched across the top of the masts with the ends in the station house. Another aerial consisted of forty wires suspended from a cable, and in planes at right angles to the plane of the masts. The highest point reached by the forty wires was about four feet, directly below the flat portion of the loop. The relation of the flat-top loop to the forty wires was in some respects similar to the relation of the grounded overhead wire to a transmission line.

On a test made between points to ground while a thunder shower was approaching, the maximum discharge from the forty wires was approximately 2 inches long, and the maximum discharge from the flat-top loop was approximately 2½ inches. We accounted for the greater discharge from the loop as due to the fact that it was higher in the air than the forty wires.

At all the Rocky Mountain stations the wire that extended the highest in the air gathered the most static, as indicated by the wireless receiver, even though the natural frequency of that wire was greater or less than that of the lower wires.

There were about three months of the year 1906, June, July, and August, when we had bad static practically all the time, except between 3 a.m. and 6 a.m. The natural frequency, *i.e.*, the number of alternations in the discharge itself, was apparently at times about 1,000,000 cycles—so estimated because the tuner was set frequently at 300 meters, and the static impulses were received better on that tuning than on others. The tuner consisted of variable inductances and a fixed condenser. I should say, from my experience with these static discharges, that they were sometimes as low in frequency as 50,000 cycles, and sometimes as high as 3,000,000 cycles per second. The discharge frequency, that is, the number of sparks at Pueblo, on one test from a seven-wire, 200-ft. aerial across a 3½-in. spark gap to ground, was one spark per forty seconds, whereas across a ⅛-in. gap, a discharge took place about every one-half second.

We accounted in different ways for the static which troubled us. One explanation was that a discharge took place between a cloud and the earth, or between two clouds, setting up electromagnetic waves which traveled out like the electromagnetic waves from our transmitter, and thus set up oscillations in our receiver antenna. Another cause that we attributed the static to was that the air about our aerial had a potential difference to earth, and discharged to earth through the aerial. Another cause was friction of winds on the wires. In our telephone receiver, when attached to the wireless detector, the static makes a buzzing noise, weak static making a faint buzzing noise, and strong static making a loud buzzing noise. The strength of this buzzing during a wind storm increased with the velocity of the wind. This may mean, however, that when more air is passing more charges are carried to the wire.

I have never known of a wireless station being struck by lightning. In one case a report came in of damage to a station due to lightning, but on investigation it was found that the operator, not realizing the conditions, had moved an antenna from its original position and had placed it above and across a 1300-volt line. The antenna guy ropes stretched and grounded the line through the receiving instruments, which acted as a fuse. This occurred at Altman, where lightning is so common and severe in the summer that a description of its activities is almost unbelievable. The aerial here was 160 ft. in height. On one occasion when I was present lightning burned out a transformer situated about 100 yds. from the wireless station. These burn-outs were said to be quite frequent. In Pueblo we had a 200-ft. tower mast at Minnequa Park, in a district in which lightning is said to strike very frequently. This mast, with 16 steel guys, broken by strain insulators, had just been completed, and a steel cable was pulled up about 100 ft. with its lower end lying on the ground. During the night lightning struck a one-story house about six squares away, but there was no evidence that it had struck the mast or any of the cables. It appears to me that the most probable explanation as to why these wireless stations were not struck is that the antennæ served as a path through which the charges above and around the antennæ gradually leaked to earth, thus preventing the accumulation of a sufficient quantity of electricity, at any one time, to cause damage upon discharging. This explanation is based on the fact that the severest static occurs shortly before a thunder storm reaches a station

D. B. Rushmore: Our knowledge of lightning phenomena is constantly increasing, and the operation of lightning arresters is each year becoming better understood. For much of this we have to thank the oscillograph.

Some caution is necessary in interpreting the results of indications caused by the puncturing of a piece of paper. It is possible for discharges to take place over series resistances which puncture paper and which have the optical effect of a considerable discharge, whereas in reality the conditions may be such that but little relief is afforded to a rise of voltage.

A great deal of engineering must be done on more or less inexact knowledge. This is true of the use of a ground wire, where it is difficult to get exact comparisons of operation under the same conditions with and without that protection.

Complete protection against lightning is being more or less closely approximated at present. From the experience which the speaker has been able to gather, it would seem that a transmission line can be practically protected against atmospheric disturbances by appropriate tower design, by the use of one or more ground wires, by the use of lightning rods and by the use of a much higher factor of safety in line insulation than has been customary. With modern protective apparatus, intelligently installed and kept in efficient working condition, it should be impossible to obtain a rise of voltage in that vicinity.

It would seem to be a fair statement to say that we are now at a point where, with the best apparatus installed in the best possible manner, and with the most careful design of transmission lines, practically complete protection against lightning can be had.

J. W. Fraser: I want to say a few words commending the work that has been done on this subject, and that has made possible the papers which we have heard this morning. The scope and thoroughness of this work is highly deserving of mention, and I am glad to see such a large attendance, and to find that so many of the members have taken such a deep interest in this work; for it is only by such intelligent and painstaking investigations that manufacturers can obtain sufficiently reliable data to give us an arrester which will be of real service under all conditions.

In the past it has been the practice of the Southern Power Company to install alternately a multigap or low-equivalent arrester, at all its sub-stations, in addition to the grounded wire over both steel and wood lines; and this company installed last autumn and this spring fourteen aluminum-cell arresters, half of one make and half of another, at various points on the lines Several severe storms have passed over different parts of the lines since these arresters were put in service, and they seem to be doing good work. On grounds these arresters have operated continuously for several minutes, apparently with very small variation in the voltage.

Although there are 315 miles of 44,000-volt line with 98 transformers, and 50 miles of 11,000-volt line with 48 transformers in service on the Southern Power Company's lines, most of which were installed last summer, only one transformer has been lost, out of the entire number in operation, from causes traceable directly to lightning. It is to the credit of the manufacturers that this is the case. True it is that a few terminals have been burned off and a few bushings broken, but such troubles are not comparable with burned-out transformers, and show the necessity for a better path to ground than the old arrester.

It has been the intention of the Southern Power Company to make a systematic study of lightning and freak voltages, but so far all that has been done was to keep an accurate log of all disturbances on lines since January 1, 1908. Of the twenty-one lightning storms which have passed over the lines since that time, eighteen were severe and three were light. Out of eight storms there was no damage of any kind. In five storms, a total of about a dozen insulators had either one or two petticoats broken off; in two storms two meters were damaged; in two storms one leg of three 44,000-volt oil switches was punctured; in one storm, one 2200-volt oil circuit-breaker blew up (no current on the transformer and the lightning struck a short secondary about 300 feet long); in one storm, transformer leads were burned off two transformers inside the case; and in two storms the line was grounded through a punctured insulator and caused considerable damage.

The most difficult thing we have to contend with is a grounded conductor. The overhead grounded line and the old form of lightning arresters seem to take care of ordinary lightning storms comparatively well, but as soon as a conductor is grounded, due to any cause, there is sure to be a fire display over the entire system and damage is inevitable. We believe, however, from the experience we have had with the aluminum-cell arrester that this arrester will be of great service in trouble of this nature. Its ability to withstand continuous discharge for some time without varying the voltage materially gives it a place unheld so far by any other arrester A rather peculiar incident happened the night before I left to come to this meeting. I had just read the part of Mr. Creighton's paper that refers to the station grounds, where he cautions every one to couple all grounds, when our superintendent of construction came in and related an experience he had had that day bearing out Mr. Creighton's warning. The superintendent had two heavy steel towers erected in concrete, one on each side of the tail-race of the Great Falls power house and was guying to an old cedar stump the end of a messenger cable which he had strung between the towers to carry conductors across. He and five of his men who had hold of this wire received a very severe shock and heard the electrolytic arrester about 200 feet away discharge and hold for an instant or two. As soon as the arc broke the men were relieved. On investigation it was observed that the end of the pipe to which the arrester was grounded was only five or six feet away from the men's feet, and that the earth was comparatively dry around the pipe, which was only a few inches in the ground.

This pipe was not installed for a ground, but for part of an old water main used in construction. It is quite evident that the current was seeking a better ground through the foundations of the steel towers, the concrete of which was still moist.

Mr. Thomas speaks about the bits of paper being punctured in various places. An insulator on our line was punctured in three separate places and shows the slag formed evenly around each hole.

W. L. Waters: I was much interested in the conclusions which Mr. Berg draws from his experiments. He finds that whenever we have an open-air arc on a circuit, we get extremely high-potential rises on the end coils of the transformers. According to his figures, we would get a potential rise equal to about 15 or 20 times normal voltage on the first 200 turns. This will probably mean that we get a potential rise of 100 to 200 times normal on the end turn of the winding, and it should be remembered that this potential rise is not a sudden strain merely, but that it continues as long as the open-air arc is on the circuit. I think that only a transformer designer can realize how serious such a potential rise would be. On large 60-cycle transformers we have up to 200 volts per turn normal potential, so if we get this sudden rise, described by Mr. Berg, it might mean 40,000 volts on the end turn of the transformer. It would not be commercially possible to insulate the transformer to stand such a high voltage between turns.

The only suggestion which Mr. Berg offers for protecting the transformer is to place a series of condensers across the various coils. There would be little difficulty in insulating the individual coils of the transformer for high voltage—the great difficulty would be in insulating the end turns of the individual coils. For these condensers to be effective, therefore, they should be connected between the various end turns of the end transformer coils, rather than across the coils themselves. I think it will be realized that the suggested remedy of putting condensers across the individual coils of the transformer would do little good, besides being unpracticable. It is well known that the weakest parts of a transformer are the various voltage taps which are brought out, and it is easily seen that the additional danger due to numerous taps being brought out from the winding to the condensers would offset any advantage which might be gained from their use. The additional cost and complication of this series of condensers would also make the size and cost of the transformer prohibitive. I think that the only practical method of protecting the transformer against these high-potential strains is the insertion of choke-coils between the transformer and line. These choke-coils will most certainly afford some protection to the windings, and it is just a question of selecting choke-coils with the required constants to give suitable protection.

I rather think, however, that Mr. Berg in his experiment has chosen conditions which are in some way different from practical operating conditions. We have been operating transformers for the past fifteen years on power circuits which are exposed frequently to open-air arcs and have done this without any extra insulation on the transformer windings and without choke-coils. According to Mr. Berg's experiment, we ought to lose our transformers every time we had an open-air arc on the circuit, and we all know that this is not the case. I think, therefore, that Mr. Berg must have had some special conditions present in his test which caused him to obtain unusual results, and that he should guard against drawing general conclusions from a limited series of special tests.

William McClellan: After some experience with lightning arresters at voltages varying from 11,000 to 60,000, I cannot help but think that the two methods of obtaining data as shown in the papers of this morning, while both valuable, fill very different places in the study of the subject.

So far as effectiveness is concerned, the speaker believes the method used by Mr. Creighton is of the very highest value, and it is with the greatest pleasure that he bears testimony to his enjoyment in reading the paper. It seems almost certain that the final solution of the problem will be reached by this method sooner than by any other.

It must be conceded that results obtained by a test-paper method can only be corroborative of the conclusions and predictions obtained from the experimental methods. As is well known in all laboratory work, results can only be obtained when conditions can be isolated, and most engineers will agree that in work of this kind isolation is well-nigh impossible so far as commercial lines are concerned. The variables are so many, the causes of each are so subtle, that it is difficult to get any positive knowledge of what the conditions are at the time the phenomenon occurs.

It would be well for all to note that the real problem at present in lightning protection arises in connection with transmission lines. It may safely be said that we can protect at present any kind of station, and all the future can do is to make this protection simpler and less expensive. We are far, however, from a solution of lightning protection to transmission lines. In this connection the writer can only repeat his opinion, expressed before, that the ground wire will be found eventually to be the only method which will give real protection. But the ground wire, to be adequate, will have to be installed in a more elaborate manner than is now customary. There is no doubt that in time to come we will build our transmission lines with as much care, and they will warrant as much expense, as a high-speed railroad right-of-way. I think we must recognize sooner or later that if the transmission line is to be protected adequately, so as to give practically continuous operation, we shall be compelled to put on it several times the expense that we do at present. The error we are making at present is in attempting to get line protection cheap.

Farley Osgood: I would ask Mr. Thomas if he can tell us from these tests something about the limits of the area of the disturbance. Not very long ago most operating engineers felt when a lightning storm came that they were likely to feel the effects of it everywhere in their system. A number of engineers now tell me that half a mile is likely to be the limit of the area disturbed. Possibly in the test made on the Taylor's Falls line this point was brought out. If I remember Mr. Vaughan's paper correctly, it indicated that one-half to three-quarters of a mile seemed to be about the limit of severe disturbances, but as an operating engineer, I feel safe in saying that we dare not have very great confidence in that statement.

I would also like to ask if any one can tell what benefits are derived from serving the phase wire near the insulator. This practice is not a general one, but some engineers follow it and they record remarkable results in the loss of a great number of insulators without the parting of the phase wire. I therefore simply bring it up as a matter for discussion.

I wish to agree with Mr. Rushmore about forming final conclusions from the results of the tests and experiments which are now going on. His reference to Mr. Thomson's chain of lightning disturbances reminds me that a year or two ago, when the sun spots were observed, and it was supposed this condition would give us a good deal of trouble, our good friends who seemed to be in pretty close touch with the folks who send us lightning storms, alarmed all the operating engineers at the prospect of some terrible lightning storms that season. These conclusions were based on very careful study, but as a matter of fact I think we had less disturbance from lightning storms that year than in any previous year.

Dugald C. Jackson: I wish to call attention to the enterprise and foresight of the manufacturers who have supported the experiments Mr. Creighton carried on, and likewise of the owners of transmission lines who have supported the experiments presented by Messrs. Vaughan and Neall. We have been this morning viewing the papers from the standpoint of the results that have already been attained. Now, these results are large, but they are merely indicative of the path to be followed toward a solution of the lightning difficulties. I believe that Dr. Kennelly is too much influenced by his experience in the telegraph art, when he throws out the inference that lightning protection for transmission lines will not be reasonably perfect in the future. We spend so much money for the insulation of transmission lines as compared with the insulation of telegraph lines, and the value of the apparatus to be protected is so great as compared with that in the telegraph lines, that we can afford to spend enough money to protect transmission lines and protect them thoroughly.

It used to be said that successful paralleling of alternators was impossible. Now it is one of the commonplace matters of engineering practice, this paralleling of alternators. Of course, now and then an accident occurs to paralleled alternators, but that does not alter the fact that paralleling of alternators is successful. Likewise, we seem to be in a fair way to soon see the "impossible" accomplished in the protection of transmission lines. The experiments that are now being carried on with transmission lines are doing more to bring us to a real knowledge of the characteristics of lightning strokes, and of the measures to use for protecting the lines from their injurious effects, than everything that went before. We should view the experiments that have been set forth in these papers from the standpoint of what they lead toward, and also from the standpoint of the great ingenuity and ability with which the work has been done,—not merely viewing what they show in completion. If such results and such methods of work as are laid down in Mr. Creighton's paper, or as are laid down in the paper that Messrs. Vaughan and Neall earlier presented, came from a laboratory of "pure science," these results and a statement of these methods would be heralded with acclaim. Coming from engineers, as they do, as part of the engineer's daily work, they are part of the craft of the engineer and we forget the tremendous labor and tremendous ability that have gone into the experiments, and our discussion is likely to tend toward criticism instead of encouragement. That does not seem to me to be in keeping with the pioneer character of the papers or fair to the art dealt with. A reasonable amount of acclaim given to the experimental results and beautiful methods used will encourage and lead toward the more rapid extension of such work, a result which is earnestly to be desired. The Institute is fortunate in having these papers before it for discussion, and I desire to express my particular admiration of the manner in which the authors conceived and executed their experiments and presented their results.

Chas. P. Steinmetz: I caution you not to accept too broadly the statement that lightning disturbances extend only over a half-mile or less. This is really not the fact. I know from my own experience that occasionally when a lightning storm passes in the Hudson valley, the lights in my house, thirty or forty miles away, go out. The statement made in the paper is correct only in that the disturbance produced by the lightning stroke, by its very abrupt discharge, extends only over a half-mile or less, possibly even over only a few poles; but internal surges produced by these lightning disturbances, as by a grounded phase resulting from the puncture of an insulator by lightning, extend over the entire system, and the latter disturbances are those which are most serious and thus most noticeable. Whereas the direct lightning stroke is only the starting point of the disturbance, the latter disturbances are really the phenomena against which we have to guard, and expect to guard, by the aluminum arrester.

With the statement made that transformers break down equally as often in the middle as at end turns, I cannot agree. It was the frequent breakdown of end turns which caused manufacturers to increase the insulation of the end turns again and again. The transformers, as they stand now, with the very heavy insulation of the end turns, may break down equally as often at the end turns as in the middle, but this merely shows that the engineering design is correct, that we have increased the insulation toward the ends so much as to give the same margin of strength throughout the entire transformer. The equal frequency of breakdown throughout the entire transformer, with the much heavier insulation of the end turns, proves that the strains are far more severe toward the ends. If we left the end turn unprotected, we would find a very disastrous state of affairs.

Regarding the weird phenomena described by Mr. Berg in his paper: it is true we can make a picture of these, as Mr Taylor shows, but what we desire Mr. Berg to give us sometime is not a mere picture—how it happened—but we expect to get equations of it.

I have seen phenomena of the same character, which are quite curious. Some years ago we built a 500,000-volt transformer—this was quite some time ago, and we knew a great deal less of very high voltages at that time than now. With the transformer fully assembled, and with the terminals brought out from the oil, we were never able to run the transformer up to full voltage. It always broke down. If we took the terminals off, below the point where they come out of the oil, leaving the transformer connected with full voltage, we could run the voltage considerably beyond 500,000, without doing any damage. It was merely a case of a small terminal capacity, and by bringing the terminals out in the air, the brush discharge produced a high-frequency oscillation, which made the transformer break down internally, at a nominal effective voltage below that which it would stand as a steady stress.

E. E. F. Creighton: In reply to Mr. Lincoln's question, of whether there was dynamic current on when these records, Figs. 3, 4, and 5, were taken, I will say there was not. Of course, if there had been dynamic current there, the arc would have continued to play and the record would have been lost. The record shows nothing but the oscillations of the circuit.

In regard to the overhead grounded wires, I think that phase of the subject has been discussed pretty thoroughly. The overhead grounded wire cannot produce complete protection, but it will, as a rule, bring the protection within the range of the insulation of the line, and in that way reduce the probability of interruptions to a very small value. When a very heavy direct discharge strikes the overhead wire, there is still a possibility that the line will arc to ground, due to "sidestroking." The farther away the ground wires are from the line wires, the less will be the danger from this source.

A number of years ago we made some laboratory experiments on the protection afforded by the overhead ground wire, and we found that the wire gave about fifty per cent. less sparking potential with the overhead grounded wire placed above it. The test was carried out by placing a large plate of sheet metal above the wires experimented upon, and regarding the plate as the cloud.

In regard to the storms themselves, there is no doubt that every storm varies in its characteristics from every other storm, to a certain extent. We might get an analogy by noting that in any dusty place, around a building or fence corner, every wind current or every wind storm that comes up has a different effect; but if you watch you will find that little currents or whirls of air will frequently form at certain places. You find the same thing with cloud effects. Out on the plains thunder clouds may appear anywhere. In the mountains the heated air in the canyons will cause thunder clouds to form repeatedly in the same location, and the mountains themselves give a direction to the winds. Although I think the direct observation of storms in general gives very little practical information in engineering, yet an attempt at classification explains some differences in their destructive effects. Not very long ago we observed a storm which was rather peculiar. It was made up of clouds in the form of an inverted cone. I was stationed at a point about two miles away from the apex of the cone, and I observed that the lightning strokes would start from all directions in the body of the cloud-cone and discharge at one particular point, the apex. The conditions are shown in the figure.

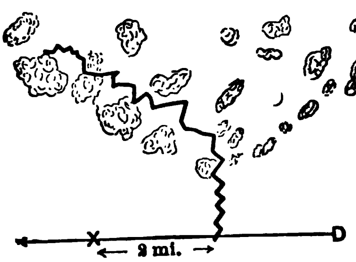


FIG. 1

At the station where the speaker was there was not even rain until some time after the lightning display ceased. The electrical storm was severe but its effect on the transmission line was negligible. There were over fifty strokes at the apex of the clouds. If the apex of the clouds had been situated directly over the station or line the destructive effects would have been great, and the protective apparatus would have been called on for its maximum discharge rate.

The distance to the point on the earth struck by the discharge was located by the well-known method of counting seconds between the instants of seeing the flash and hearing the thunder, and allowing five seconds to the mile. Since the apex of the cloud was only ten seconds distant and the thunder would roll for fifteen seconds after it started, some confusion would naturally be experienced unless the conditions were analyzed. There were at least three definite relations between the thunder and lightning which a fortunate situation relative to the storm aided in checking.

1. There was the flash to ground, followed about four seconds afterward by mild rolling thunder, which increased in intensity up to ten seconds, and then ended in a loud crash. This thunder was due to a discharge which started in the clouds directly overhead at an elevation of nearly a mile and darted to the apex, gathering a greater quantity of electricity as it went. This increase in the quantity of electricity is not the only factor affecting the noise of the thunder. The wet atmosphere in the clouds relative to the dry atmosphere between cloud and earth was a good conductor. There would therefore be less tendency for the discharge in the cloud to collect in one streak. Between these two effects, the noise of the rolling thunder increased despite the fact that it came to me from a greater distance.

2. After an interval of ten seconds following the flash to earth the thunder started with a heavy crash, and then rolled during eight to fifteen seconds, gradually diminishing in intensity. This thunder was due to a stroke coming from the farther side of the cone to the apex.

3. After the flash to earth there was an interval of ten seconds and then a crash of thunder with little or no rolling. This thunder was due to a stroke moving through the clouds to the apex at right angles to the point of observation. All the path of discharge being at nearly the same distance the sound from the different portions arrived at the same time, hence the lack of rolling.

Since the strokes occurred at intermediate angles also, these three effects were obtained only to a lesser degree.

The theory of the formation of thunder clouds leads to the conclusion that this conical form of storm cloud occurs frequently on the line.

Mr. Taylor questions the use of the word lightning to express all abnormal conditions of potential on the line. That name is due to Dr. Steinmetz—it was a very convenient term, and we adopted it. Subsequently, the use of the word "lightning" was discussed by several interested engineers, with the result that Dr. Steinmetz and the writer agreed to use the term lightning only in its time-honored sense—cloud discharges and their induced effects. Some general term is needed to cover the various abnormal surges which occur on a transmission line. Several words were discussed but none agreed upon.

Mr. Taylor brings up the question of lightning frequency. I think my statements will be clear if one accepts the general term lightning as any abnormal condition of tension on the line. A frequency of one million cycles per second was measured by a number of coils, described in the paper, and I am very glad to get the opinion of wireless-telegraph engineers that they also have noticed frequencies of that order, measured by a different method. Dr. Steinmetz has made calculations on the probable frequency of cloud discharges, and the value has come out of the order of a million cycles. A cloud discharge may have a frequency of only fifty thousand, or it may have no frequency at all—may be a non-oscillatory discharge. There is reason to believe that this latter condition may obtain under some circumstances. The lightning is gathering from perhaps miles around, or may be merely passing through a few acres of cloud, but in gathering it has to pass through a high resistance—pass from point to point in the clouds, in the form of brush discharge. Therefore, it seems reasonable to assume that certain lightning strokes can occur without any oscillations at all.

Mr. Taylor brings up the question of the resistance of the earth independent of the contacts. The usual contact resistance of an ordinary pipe earth, if well made, will be about fifteen ohms. It may be considered that the resistance is concentrated in the immediate neighborhood of the pipe. In the case referred to, the data is given for a condition out in the Rocky Mountains, where as the term indicates, everything is rocky—the mountains are composed of solid rocks. The rock is dry, hard, and of low conductivity. The conducting earth between the two points measured was in a very narrow canyon, consequently the resistance depended upon the distance. In another case the earth resistance was very much less, being only a few ohms. In a neighborhood where there is plenty of good loamy soil, and plenty of moisture, there is no doubt that the actual earth resistance, independent of the local and contact resistances, would be very small.

In regard to the questions brought up in connection with Mr. Berg's paper, I wish to corroborate the statement made by Mr. Berg, that the biggest problem we have to-day is not the protection against cloud lightning, but protection against the internal surges. Some of the worst conditions observed last summer in Colorado were due to these internal surges, combined with short-circuits. This combination gives the worst condition that can exist on the line, outside of a direct stroke. A direct stroke affects only a small locality, whereas a grounded phase, combined with a short-circuit, may affect the whole circuit, and usually does.

There is just one other point I wish to take up: the conditions of further study. Personally, I am indebted to a number of operating engineers who have assisted in this work; and the operating engineer has put up to him part of the problem which he must solve himself. So far as we are able to do so, we shall continue to study; but from the factory end we cannot hope to solve the entire problem, because the conditions on one line are not the same as on another. The problem relates to protection against accidentally grounded phases, the installation of the number of lightning arresters necessary to effect this protection, and the spark potential of the lightning arrester.

Now, in order to make a lightning arrester that is marketable, it is essential to keep the price down to a value which is comparable to the cost of the apparatus to be protected—say the transformer, the generator, or whatever it may be. This condition has necessitated the use of a gap in series with an aluminum arrester. The questions are: what gap-setting to use and how many of these aluminum arresters must be placed on a transmission system; that is, how many stations must be protected with the aluminum arrester, to give protection to all the rest? For example, if we have thirty stations, will the protection of ten of them with aluminum arresters protect the balance against internal surges?

E. J. Berg: I have purposely refrained from giving any theory for the action of these arcing grounds, because an incomplete theory is worse than no theory at all. I believe, however, that Mr. Taylor's theory will not apply. Referring to the diagrams showing grounding of one side of the open delta, you see that the transformer nearest to ground is subjected to a voltage which corresponds to 3.25 inches striking distance. At that time the striking distance across the outside transformer is 3.21 inches. If Mr. Taylor's theory were correct, the striking distance across this latter transformer would have been 2 inches.

It may be of interest to add that at the time of such an arcing ground not only are the end turns subjected to high voltages, but also to considerably greater current, and correspondingly greater heating, than the other turns.

Regarding Mr. Waters' discussion: I tried, as you see from the paper, to overcome the difficulties discussed in the paper, by the use of reactive coils, but was unable to reduce materially the stresses incidental to these arcing grounds. This was true even when using a large number of coils, the turns of which were approximately one-sixth of the total number of turns in the transformer. These coils did not contain any iron, but they were of the same dimensions as the transformer coils.

Regarding the stresses on the end turns, Mr. Waters is no doubt perfectly right, but it may interest you to know that the company with which I am connected insulates the end turns of its high-potential transformers for one hundred to two hundred times the normal voltage. For very high-voltage transmission, it is likely that delta-delta connection will not be used, but instead the delta-Y grounded neutral, with which an arcing ground can not occur since such a ground means a short-circuit, and consequently the line has to be cut out of service.

Percy H. Thomas: I wish first to say a word about Mr. Berg's paper. I think it is very important here to draw a distinction in arcs, so-called. The arc which carries a great deal of current, and in which there is no cooling of the arc between alternations, and the type of arc that is under discussion, in which apparently there is a practical healing of the gap between alternations, are entirely different things. I think it is clear that these rises of potential are produced by that type of arc which drops out between alternations; in other words, it is but little more than a constant repetition of the condition of the initial ground. It is pretty well known that when a transmission wire grounds, the charge from the capacity to ground starts oscillations in the system and produces waves and reflections of the same which may cause a rise of potential. This may have in the simple case a value twice normal, or in more complex cases somewhat more than this, on account of the presence of series inductance and on account of variations of line capacity, etc.; but the action does not give enormous voltages, and introduces no new principles or features. I think this point of view will explain a great many of the phenomena reported in Mr. Berg's paper. I do not find here anything new, in the way of a danger which we have not heretofore recognized. By any one who is familiar with experimental work of that character, the difference in the types of these arcs is easily detected. There is a rough, irregular sound in all arcs where there is a large percentage of "healing" in the gaps between alternations.

Another thing, which has tended to increase the apparent rise of potential reported in Mr. Berg's paper, is the fact that he has given jumping distances, and not voltages. This causes a considerable exaggeration with voltages higher than 25,000.

I also wish to make one or two comments on Mr. Creighton's paper. I was going to raise the same point as was raised by Mr. Taylor in connection with the production of a lightning frequency of 3,000 alternations. I see the explanation of this low frequency is that the term "lightning" does not indicate cloud lightning, but the natural discharge of the line. I want to protest against this use of this word "lightning." I do not think there is anything that will cause us more confusion than to use the term generally for all sorts of discharges in the circuit and also for all disturbances outside, as well as the natural lightning phenomena. If we could all get together and agree that we would give the word "lightning" a certain new meaning it would perhaps not be misunderstood. but we are writing for a great many people over whom we have no control and they will not understand it at all.

Another point: In regard to the word "static", I wish to defend Mr. Berg. If there is one term that we need in the business, in electrical high-tension work, it is a general term to describe these disturbances which come from discharges or surges in the line, due to other than normally generated electromotive force. These disturbances are entirely different in their nature from the so-called dynamic electricity. I know of no word anywhere which nearly so well expresses the idea as the word "static."

Chas. P. Steinmetz: Lightning.

Percy H. Thomas: The word "static" is used broadly at the present time with this significance. It is true, surges are not *static* electricity, but this seems to me a meaningless objection. I wish strongly to urge the general adoption of this term. No one will be misled, and it fills a long-felt want.

I wish to inquire of Professor Creighton, whether the use of salt, in perfecting ground connections using iron, would not be a pretty dangerous recommendation, on account of the corrosion. It is well enough for experimental purposes, to determine losses, but it seems to me would be undesirable for use in permanent grounds.

I wish to state that in the past I have been inclined to doubt the efficiency of overhead ground wires and their effectiveness, but at the present time I am pretty well convinced that ground wires give the best and almost the only hope of completely protecting transmission lines against lightning. The point I attempted to make in my paper, and which seems to have been taken too broadly, is that the particular experiments referred to in the paper have not proved that these particular ground wires were effective. If these ground wires are properly installed, I believe they offer a very promising remedy. The danger is, first, that as they are ordinarily used, ground wires are not sufficiently separated from the transmission wires, and lightning striking them will also jump to the wire itself; and second, that they are not so located that the lightning will always strike them first. There is always a probability that there is one transmission wire, or possibly two, which is at a lower potential with regard to the cloud than the ground wire itself. There will be a tendency for a discharge to pick out this transmission wire rather than the ground wire.

I cannot agree with Dr. Steinmetz that it is not possible to distinguish between the effect of a bound charge and a direct stroke of lightning. To my mind, this difference is vital, for the reason that the character of protection required will be different for the two types of disturbances. If it is a matter of a bound charge, you must have a static shield, which is difficult to obtain completely, but the intercepting of a direct stroke may not be so difficult. There can be no doubt that all these types of disturbances do affect the line, whether it is a bound charge, direct stroke or electromagnetic induction. The vital question is, which sort is it that punctures insulators and splits the pole? If we find which one of them does that real harm, we can then protect against that, and let the others go.

Mr. Vaughan's paper shows that there are a tremendous number of lightning disturbances which do not go over the insulators. I think a careful study of the paper proves that the attack which did the damage came from the air.

Mr. Osgood asks about the extent of the disturbances shown by the Taylor's Falls tests. There are two criteria: first, the individual stroke, which I believe is felt in severe form on only a very few poles; and second, the static waves in the line which are of limited energy and voltage but which travel all over the system. The evidence in Mr. Vaughan's paper and other evidence corroborate this.

I wish to protest against the statement that we find about three or four times on every occasion when we have a lightning-arrester paper, that this sort of data which is presented should not be taken seriously, that it will not do to infer too much from it, that we must reserve our judgment, that it is necessary to prove these things before people can accept them, etc. It seems to me that is a narrow view to take of the subject. If all had taken that view, we would know almost nothing about lightning at the present time. One or two examples from other branches of scientific work may be called to mind to show how untrue such a position is. Take the investigations of Hertz, who drew inferences from ordinary microscopic sparks in an exploring coil—the theory he built up has proved itself to be true. Our data are fully as illustrative. Take the case of radioactivity, the results that have been obtained from the study of very minute and apparently most insignificant measurements. Similar is the work of J. J. Thomson and others on the ionization of gases. All these results were worked out from data naturally much more inconclusive than the data we have on lightning experiments.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 30, 1908.

THREE-PHASE POWER-FACTOR

BY AUSTIN BURT

Based on the commonly accepted definition of power-factor, as " The ratio of true power to volt-amperes ", there can be no single factor that will exactly express such a physical relationship in a delta-connected, unsymmetrical, three-phase system.

It is possible, however, to determine, by practical methods, the weighted mean of the three power-factors of the single-phase paths of such a three-phase system, and to express that value by a single-factor. It has been suggested that such a factor might have importance under certain commercial conditions.

It is the purpose of this paper, first, to derive from the various relations that exist between the electromotive forces and currents in a three-phase, delta-connected system, a general expression which will enable the mean power-factor to be determined exactly; and, secondly, to develop a method by which the required values employed in the above expression may be readily determined from the standard switchboard instruments.

It is proposed, therefore, to find an expression for the total energy volt-amperes and for the total volt-amperes in the general case of a three-phase system in which the electromotive forces and currents in the single-phase paths may have any assigned value and phase relation. The ratio of these two expressions will be the desired mean power-factor. The total volt-amperes will be taken as derived from the total wattless volt-amperes and the total energy volt-amperes, or, in other words, from the sum of the wattless volt-amperes and from the sum of the energy volt-amperes existing in each single-phase path.

In the simple case of a single-phase system let

E = the impressed electromotive force
I = the current in the circuit resulting from inductive conditions in the receiver
ϕ = time-angle between E and I.

Fig. 1 will represent vectorially such a single-phase system. Then if the energy volt-amperes be represented by P, and wattless volt-amperes by P_w, we have,

$$P = I \cos \phi \, E \tag{1}$$

$$P_w = I \sin \phi \, E \tag{2}$$

From the definition of power-factor we have,

$$\text{power-factor} = \frac{P}{I\,E} = \frac{I \cos \phi \, E}{I\,E} = \cos \phi \tag{3}$$

and,

$$\phi = \cos^{-1} \text{(power-factor)} \tag{4}$$

from (1) and (2)

$$I\,E = \frac{P}{\cos \phi} = \frac{P_w}{\sin \phi} \tag{5}$$

and by multiplication,

$$\frac{\sin \phi}{\cos \phi} = \frac{P_w}{P} = \tan \phi \tag{6}$$

then from (6) and (4),

$$\phi = \tan^{-1} \left(\frac{P_w}{P}\right) = \cos^{-1} \text{(power-factor)} \tag{7}$$

It is seen, therefore, that the angle ϕ, whose tangent is the ratio of the wattless ampere-volts to the energy ampere-volts, will give directly the power-factor from its cosine. A general expression for the total wattless ampere-volts and the total energy ampere-volts in a three-phase system, gives a ratio whose value is a weighted mean of the similar ratios of the several single-phase paths, and the angle whose tangent is this mean ratio gives the mean power-factor desired from its cosine.

In the three-phase system under consideration the total wattless ampere-volts is the algebraic sum of the wattless ampere-volts, and the total energy ampere-volts is the sum of the energy ampere-volts in each of the three single-phase paths of the system.

Such a three-phase system is represented by the vector diagram in Fig. 2. Let the impressed electromotive forces and currents in the single-phase windings be represented respectively by E_{ab}, E_{bc}. E_{ca}, and i_a, i_b, i_c, and the phase relations between the several electromotive forces and currents by α', β', γ', with the additional convention that angles measured counter clockwise are lagging, and measured clockwise they are leading.

In Fig. 2, then, the delta $(a\,b\,c)$ represents the value and

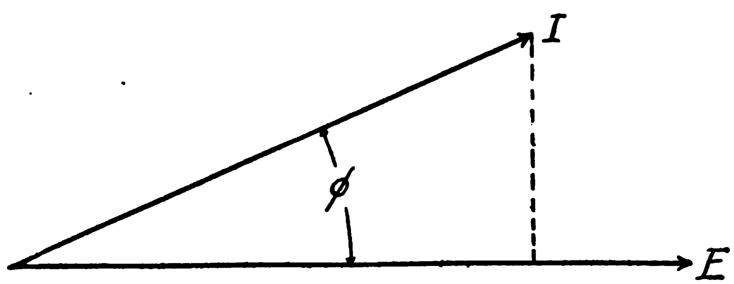


FIG. 1

phase relation between any selected values of E_{ab}, E_{bc}, and E_{ca}. The current in phase $a\,b$ and its phase relation to E_{ab} is represented by vector i_a at angle α' with E_{ab}. Similarly the currents in phases $b\,c$ and $c\,a$ are represented by vectors i_b at b and i_c at c, making lag-angles β' and γ' respectively with E_{bc} and E_{ca}. It should be remarked that angles α', β' and γ' could just as well have been taken leading as lagging.

The star or line current will be the resultant of the currents in any two adjacent paths; that is, the current at a will be the resultant of the single-phase current in $c\,a$, or i_c, and the current in $a\,b$, or $-i_a$.

i_c is represented at a by the broken vector $a\,a''$, and $-i_a$ by vector $a\,a'$. The resultant of these two vectors, I_a, therefore represents, in length and position, the line current at a. Similarly, the line current at b is the resultant of i_a and $-i_b$, which are represented at b by $b\,b''$ and $b\,b'$ respectively. Therefore, vector I_b represents, in length and position, the line current at b. And again, at c, the vector I_c is the resultant of i_b and $-i_c$, represented by the vectors $c\,c''$ and $c\,c'$, and it therefore represents the line current at C.

This diagram therefore illustrates graphically the essential

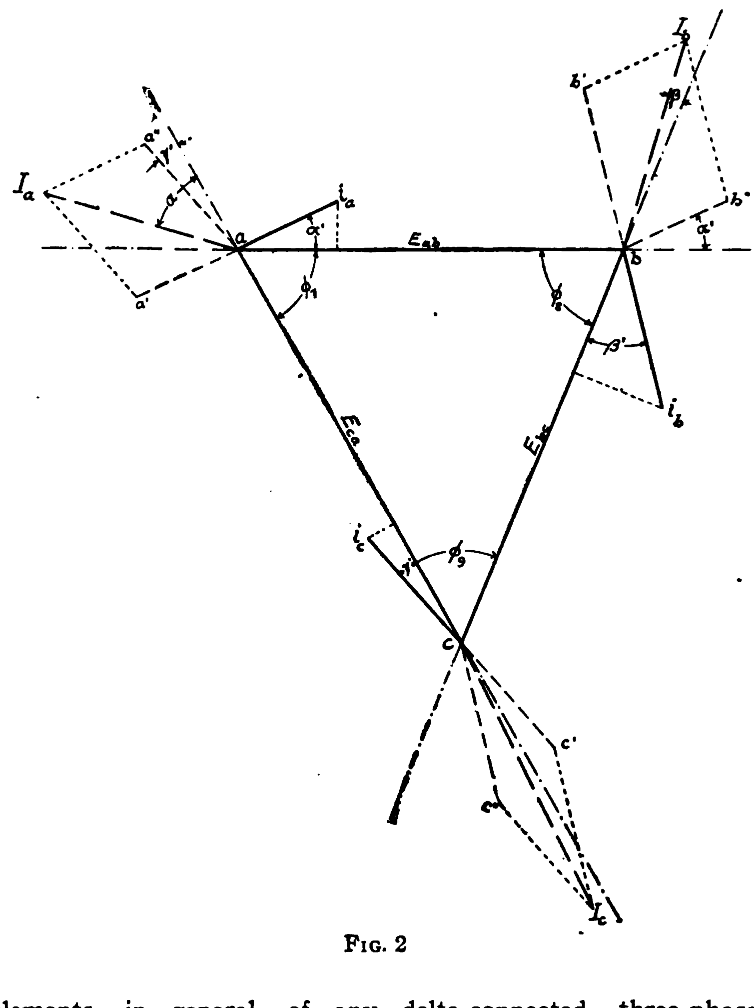


FIG. 2

elements, in general, of any delta-connected, three-phase system.

The energy ampere-volts in phase $a\,b$, in phase $b\,c$, and in phase $c\,a$ are then, if P_{ab}, P_{bc}, and P_{ca} represent the respective single-phase paths,

$$P_{ab} = i_a \cos \alpha, E_{ab} \tag{8}$$

$$P_{bc} = i_b \cos \beta' E_{bc} \tag{9}$$

$$P_{ca} = i_c \cos \gamma' E_{ca} \tag{10}$$

adding (8), (9) and (10) for total energy ampere-volts,

$$P = i_a \cos \alpha' E_{ab} + i_b \cos \beta' E_{bc} + i_c \cos \gamma' E_{ca} \tag{11}$$

Similarly the wattless ampere-volts, if $(P_w)_{ab}$, $(P_w)_{bc}$ and $(P_w)_{ca}$ represent the respective single-phase paths, are,

$$(P_w)_{ab} = i_a \sin \alpha' E_{ab} \tag{12}$$

$$(P_w)_{bc} = i_b \sin \beta' E_{bc} \tag{13}$$

$$(P_w)_{ca} = i_c \sin \gamma' E_{ca} \tag{14}$$

adding (12), (13) and (14) for total wattless ampere-volts,

$$P_w = i_a \sin \alpha' E_{ab} + i_b \sin \beta' E_{bc} + i_c \sin \gamma' E_{ca} \tag{15}$$

Since it is ordinarily inconvenient, if not impossible, to make measurements in the single-phase paths of a three-phase system it is required to find more useful expressions than (11) and (15). General expressions, based on and equal to (11) and (15), with external values for electromotive forces and currents, may be derived by a consideration of the relations existing in vector diagram, Fig. 3. This diagram is in all essential particulars an exact duplicate of Fig. 2. It is desired to prove from it that the following general proposition is true: that for any selected position of point O whatsoever, with lines $O\,e$, $O\,f$ and $O\,g$ passing through the delta vertices a, b, and c, respectively, the sum of the products of the projection $a\,e$, of line-current vector I_a on $O\,e$, by $O\,a$, and the projection $b\,f$, of line current I_b on $O\,f$, by $O\,b$, and the projection $c\,g$, of line-current vector I_c on $O\,g$, by $O\,c$ is equal to P the total energy volt-amperes and therefore equal to and may be substituted for equation (11).

Similarly, it is desired to prove that the sum of the products of $e\,a''$ by $O\,a$, and $f\,b''$ by $O\,b$ and $g\,c''$ by $O\,c$ is equal to P_w the total wattless volt-amperes, and therefore equal to and may be substituted for equation (15).

Expressing these statements in form it is desired to prove that,

$$P \;= I_a \cos \alpha'' \, O\,a + I_b \cos \beta'' \, O\,b + I_c \cos \gamma'' \, O\,c \qquad (16)$$

$$P_w = I_a \sin \alpha'' \, O\,a + I_b \sin \beta'' \, O\,b + I_c \sin \gamma'' \, O\,c \qquad (17)$$

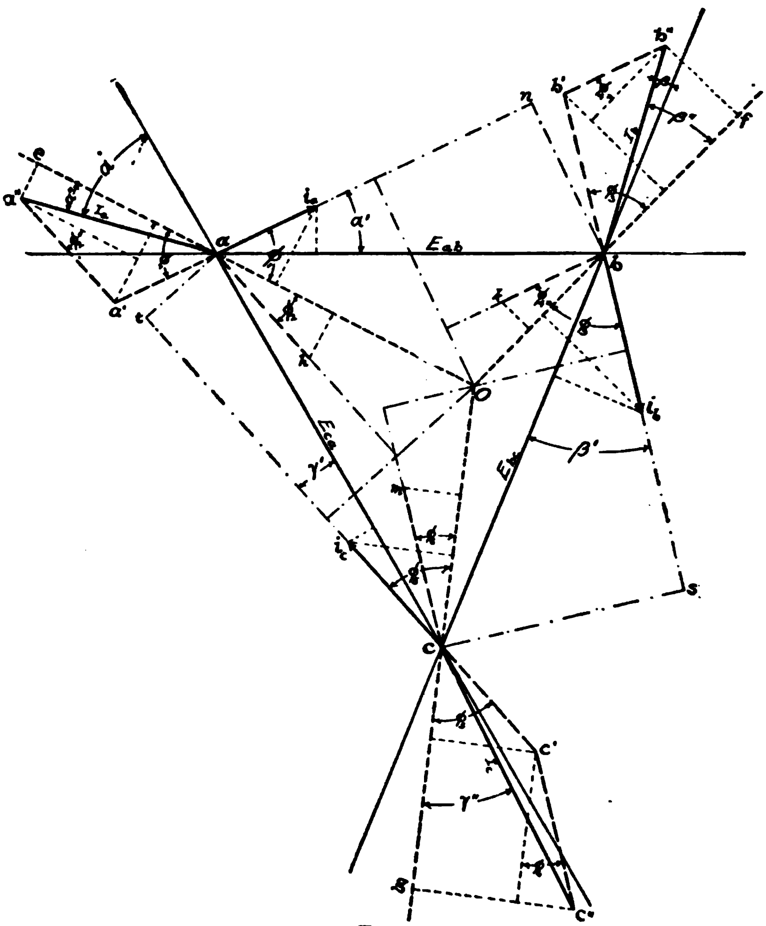


FIG. 3

Referring, successively, to the following pairs of triangles, $a\,O\,b$ and $a\,n\,b$, $b\,O\,c$ and $b\,s\,c$, $c\,O\,a$ and $c\,t\,a$, and noting that $b\,k$ is equal to and parallel with vector i_a, that $c\,m$ is equal to and parallel with vector i_b, and, finally, that $a\,h$ is equal to and parallel with vector i_c, we have the following set of equations:

$$i_a E_{ab} \cos \alpha' = i_a O a \cos \phi_1 + i_a O b \cos \phi_4 \qquad (18)$$

$$i_b E_{bc} \cos \beta' = i_b O b \cos \phi_3 + i_b O c \cos \phi_6 \qquad (19)$$

$$i_c E_{ca} \cos \gamma' = i_c O c \cos \phi_5 + i_c O a \cos \phi_2 \qquad (20)$$

$$i_a E_{ab} \sin \alpha' = i_a O a \sin \phi_1 - i_a O b \sin \phi_4 \qquad (21)$$

$$i_b E_{bc} \sin \beta' = i_b O b \sin \phi_3 + i_b O c \sin \phi_6 \qquad (22)$$

$$i_c E_{ca} \sin \gamma' = i_c O c \sin \phi_5 - i_c O a \sin \phi_2 \qquad (23)$$

adding (18), (19), and (20) and referring to (11), we have,

$$i_a \cos \alpha' E_{ab} + i_b \cos \beta' E_{bc} + i_c \cos \gamma' E_{ca} = P =$$
$$(i_a \cos \phi_1 + i_c \cos \phi_2) O a + (i_b \cos \phi_3 + i_a \cos \phi_4) O b +$$
$$(i_c \cos \phi_5 + i_b \cos \phi_6) O c \qquad (24)$$

but from Fig. 3, by inspection,

$$(i_a \cos \phi_1 + i_c \cos \phi_2) O a = (a\, a' \cos \phi_1 + a'\, a'' \cos \phi_2) O a = a\, e.$$
$$O a = I_a \cos \alpha'' O a \qquad (25)$$

and

$$(i_b \cos \phi_3 + i_a \cos \phi_4) O b = (b\, b' \cos \phi_3 + b'\, b'' \cos \phi_4) O b = b\, f.$$
$$O b = I_b \cos \beta'' O b \qquad (26)$$

and

$$(i_c \cos \phi_5 + i_b \cos \phi_6) O c = (c\, c' \cos \phi_5 + c'\, c'' \cos \phi_6) O c = c\, g.$$
$$O c = I_c \cos \gamma'' O c \qquad (27)$$

substituting these results in (24) we have,

$$P = I_a \cos \alpha'' O a + I_b \cos \beta'' O b + I_c \cos \gamma'' O c \qquad (28)$$

thus proving equation (16).

Similarly adding (21), (22), and (23), there are, referring also to (15),

$i_a \sin \alpha' E_{ab} + i_b \sin \beta' E_{bc} + i_c \sin \gamma' E_{ca} = P_w =$
$(i_a \sin \phi_1 - i_c \sin \phi_2) O a + (i_b \sin \phi_3 - i_a \sin \phi_4) O b +$
$(i_c \sin \phi_5 + i_b \sin \phi_6) O c$ (29)

but from Fig. 3 by inspection,

$(i_a \sin \phi_1 - i_c \sin \phi_2) O a = (a a' \sin \phi_1 - a' a'' \sin \phi_2) O a = e a''.$
$O a = I_a \sin \alpha'' O a$ (30)

and

$(i_b \sin \phi_3 - i_a \sin \phi_4) O b = (b b' \sin \phi_3 - b' b'' \sin \phi_4) O b = f b''.$
$O b = I_b \sin \beta'' O b$ (31)

and

$(i_c \sin \phi_5 + i_b \sin \phi_6) O c = (c c' \sin \phi_5 + c' c'' \sin \phi_6) O c = g c''.$
$O c = I_c \sin \gamma'' O c$ (32)

substituting these results in (29) we have,

$$P_w = I_a \sin \alpha'' O a + I_b \sin \beta'' O b + I_c \sin \gamma'' O c \quad (33)$$

thus proving equation (17).

Equations (28) and (33) are general expressions for any possible location of point O. If, therefore, point O be taken at vertex c in Fig. 3 there are:

$\alpha'' = \alpha \qquad O a = E_{ca}$
$\beta'' = \beta \qquad O b = E_{bc}$
$O c = 0$

substituting these values in (28) and (33) there are:

$$P = I_a \cos \alpha E_{ca} + I_b \cos \beta E_{bc} \quad (34)$$

$$P_w = I_a \sin \alpha E_{ca} + I_b \sin \beta E_{bc} \quad (35)$$

Let $$P_{ca} = I_a \cos \alpha E_{ca} \quad (36)$$

$$P_{bc} = I_b \cos \beta E_{bc} \quad (37)$$

then from (34),

$$P = P_{ca} + P_{bc} \quad (38)$$

A standard three-phase wattmeter, consisting essentially of two single-phase measuring elements, if placed in the system represented by Fig. 2, with the current coil of one element in line current represented by vector I_a and electromotive force coil across phase $c\,a$, and with the current coil of the second element in line current represented by vector I_b and electromotive force coil across phase $b\,c$, will measure by the first element that portion of total power, P, expressed by P_{ca}, and by the second element that portion expressed by P_{bc}, the two combined giving the total energy ampere-volts, P.

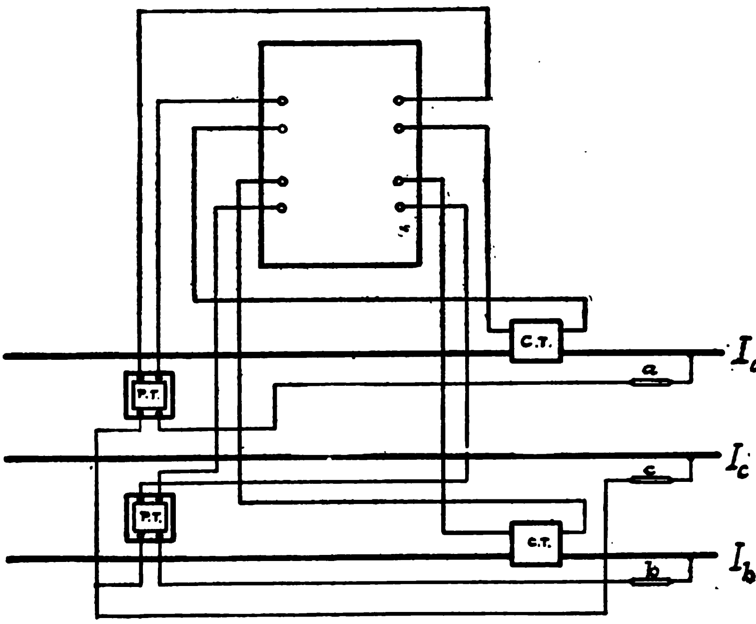


FIG. 4

It will be observed by a comparison of (34) and (35), that P_w may be derived from P by substituting the sines of α and β for the cosines, and further it will be observed, that α and β may be obtained from (36) and (37) provided the single-phase elements of the three-phase wattmeter could be read separately.

A method for accomplishing this result consists in causing to become inoperative, first one element and then the other, by opening the potential circuit of the element. Fig. 4 shows a standard connection of a three-phase switchboard wattmeter operated by current and potential transformers. At a b and c

are shown the usual primary fuses for the potential transformer. I_a, I_b and I_c are the line currents. By removing fuse b the wattmeter element operated by current I_b and electromotive force across $b\,c$ becomes inoperative and a reading taken from the instrument is expressed by (36) or,

$$P_{ca} = I_a \cos \alpha \, E_{ca}$$

from which,

$$\operatorname{Cos} \alpha = \frac{P_{ca}}{I_a \, E_{ca}} \qquad (39)$$

Similarly by the removal of fuse a, Fig. 4, the other element becomes inoperative, and by replacing the first fuse, a second reading from the instrument is expressed by (37), or

$$P_{bc} = I_b \cos \beta \, E_{bc}$$

from which,

$$\operatorname{Cos} \beta = \frac{P_{bc}}{I_b \, E_{bc}} \qquad (40)$$

As line currents, I_a and I_b, and voltages, E_{ca} and E_{bc}, are readily found from standard switchboard ammeters and voltmeters, (39) and (40) can be easily solved for α and β, the sines of which substituted in (35) will give the total wattless volt-amperes, P_w.

Having demonstrated that equations (34) and (35) are true and derived from general expressions for P and P_w, and that they may be solved practically, it follows that values determined by them when substituted in equation (7) will give the desired value for ϕ and thus also the proposed mean power-factor.

It may be of interest to take the simple case of a single-phase load in the three-phase system under consideration, and derive the power-factor by this method.

The same values may be assumed as represented by Fig. 2, with the single-phase inductive load in phase $a\,b$, and represented by i_a. Currents i_b and i_c will be absent from phases $b\,c$ and $c\,a$, and therefore equal to zero.

This condition of affairs is represented more plainly by Fig. 5, in which,

$$\begin{array}{lll} I_a = i_a & \phi_1 = \alpha = \alpha' + \phi_7 & O\,a = E_{ca} \\ I_b = i_a & \phi_4 = \beta = \phi_8 - \alpha' & O\,b = E_{bc} \\ I_c = 0 & & O\,c = 0 \end{array}$$

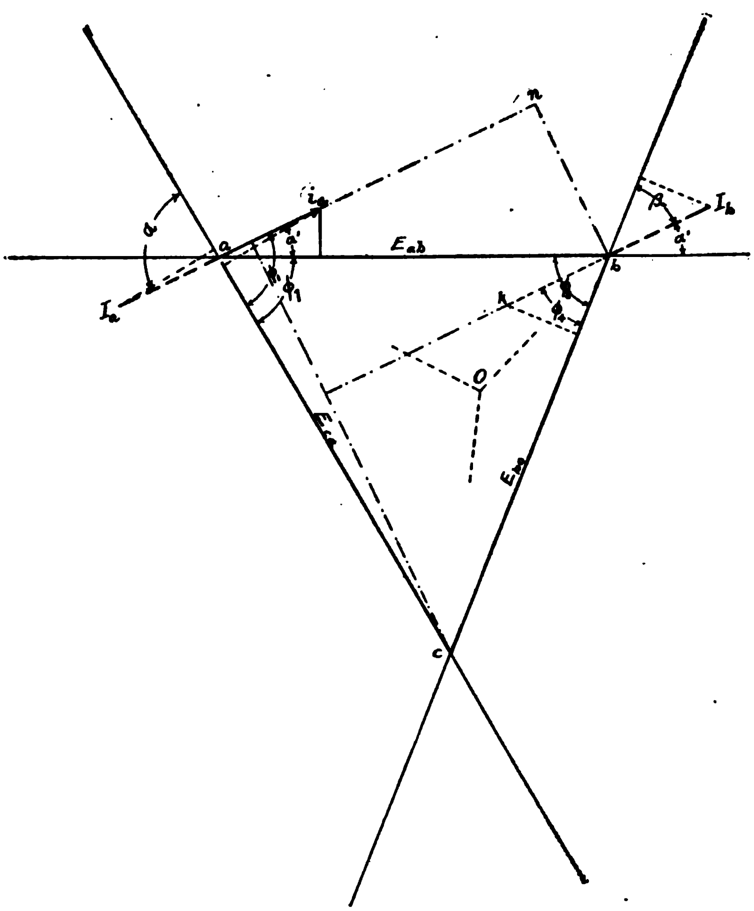


Fig. 5

substituting these values in equation (24), and (29)

$$P = I_a \cos(\alpha' + \phi_7)\, E_{ca} + I_b \cos(\phi_8 - \alpha')\, E_{bc} \tag{41}$$

$$P_w = I_a \sin(\alpha' + \phi_7)\, E_{ca} - I_b \sin(\phi_8 - \alpha')\, E_{bc} \tag{42}$$

But it is seen from Fig. 5 that,

$$E_{ca} \cos (\alpha' + \phi_7) + E_{bc} \cos (\phi_8 - \alpha') = E_{ab} \cos \alpha' \qquad (43)$$

$$E_{ca} \sin (\alpha' + \phi_7) - E_{bc} \sin (\phi_8 - \alpha') = E_{ab} \sin \alpha' \qquad (44)$$

substituting in (41) and (42) and dividing (42) by (41), remembering that $I_a = I_b = i_a$, we have,

$$\text{Tan } \phi = \frac{P_w}{P} = \frac{E_{ab} \sin \alpha' \, i_a}{E_{ab} \cos \alpha' \, i_a} = \tan \alpha' \qquad (45)$$

Therefore $\phi = \alpha'$ and since their cosines are necessarily equal, the mean power-factor must equal the power-factor of the single-phase winding $a\,b$.

As this is a general solution of the single-phase case, it follows that it will be true for any assigned conditions as to electromotive force, current, or phase-relation.

Assuming the above single-phase load to be non-inductive, α' will then be zero and from (45),

$$\text{Tan } \phi = \frac{P_w}{P} = \frac{E_{ab} \sin 0 \, i_a}{E_{ab} \cos 0 \, i_a} = \frac{0}{1} = 0$$

$0 = \cos^{-1} (1)$, therefore power-factor equals unity.

Still another simple case is that of the balanced three-phase load, equal electromotive forces and uniform phase-relations in the single-phase windings. For convenience, this phase relation will be taken as 30° lagging.

Referring to Fig. 2 there will be,

$$\begin{aligned} E_{ab} &= E_{bc} = E_{ca} = E \\ i_a &= i_b = i_c = i \\ \alpha' &= \beta' = \gamma' = 30^\circ \\ I_a &= I_b = I_c = I \end{aligned}$$

By inspection from Fig. 2,

$$\phi_7 = \phi_8 = \phi_9 = 60^\circ$$

and

$$\begin{aligned} \text{angle } a'\,a\,a'' &= \phi_7 + \alpha' - \gamma \\ &= 60^\circ + 30^\circ - 30^\circ = 60^\circ \end{aligned}$$

therefore, since $a\,a' = a\,a'' = i$, there is

$$\alpha = \tfrac{1}{2}\text{ angle } a'\,a\,a'' + \gamma' = 30^\circ + 30^\circ = 60^\circ$$

and also,

$$\begin{aligned}\text{angle } b'\,b\,b'' &= \phi_s + \beta' - \alpha' \\ &= 60^\circ + 30^\circ - 30^\circ = 60^\circ\end{aligned}$$

therefore, since $b\,b' = b\,b'' = i$, there is

$$\beta = \tfrac{1}{2}\text{ angle } b'\,b\,b'' + \alpha' - \phi_s = 30^\circ + 30^\circ - 60^\circ = 0^\circ$$

substituting these values in (34) and (35),

$$\begin{aligned}P &= I\,E\cos 60^\circ + I\,E\cos 0^\circ \\ &= I\,E\,(\tfrac{1}{2}+1) = 3/2\,I\,E \\ P_w &= I\,E\sin 60^\circ + I\,E\sin 0^\circ \\ &= I\,E\,(\tfrac{1}{2}\sqrt{3}+0)\end{aligned}$$

substituting in (7),

$$\phi = \tan^{-1}\left(\frac{\tfrac{1}{2}\sqrt{3}\,I\,E}{\tfrac{3}{2}\,I\,E}\right) = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = 30^\circ$$

Therefore,

$$\text{power-factor} = \cos 30^\circ$$

In conclusion, the following practical illustration will emphasize the proposed method. It may be remarked in passing that the values taken are those used in Fig. 2.

Using the same nomenclature as in the previous demonstration there are,--

$E_{ab} = 2.050$ kilovolts.	$I_a = 214.8$ amperes.
$E_{bc} = 2.248$ "	$I_b = 228.5$ "
$E_{ca} = 2.400$ "	$I_c = 312.2$ "
$P_{ca} = 371.49$ kilowatts,	$P_{bc} = 511.30$ kilowatts

from (38),

$$P = 371.49 + 511.30 = 882.79 \text{ kilowatts.}$$

from (39) and (40),

$$\cos\alpha = \frac{371.49}{214.8 \times 2.400} = \cos\,(43^\circ\,54')$$

$$\text{Cos } \beta = \frac{511.30}{228.5 \times 2.248} = \cos (5^\circ\ 36')$$

whence,

$$\text{Sin } \alpha = \sin (43^\circ\ 54') = 0.6935$$
$$\text{Sin } \beta = \sin (5^\circ\ 36') = 0.0977$$

substituting in (35),

$P_w = 214.8 \times 0.6935 \times 2.400 + 228.5 \times 0.0977 \times 2.248 = 357.46 + 50.18 = 407.64$ wattless kilovolt-amperes.

Substituting these values of P and P_w in (7),

$$\phi = \tan^{-1} \left(\frac{407.64}{882.79} \right) = 24^\circ\ 47'$$

therefore,

$$\text{power-factor} = \cos (24^\circ\ 47') = 0.908.$$

Discussion on "Three-Phase Power-Factor." Atlantic City, N. J., June 30, 1908

Comfort A. Adams: I think that at least a part of Mr. Burt's demonstration may be rendered less mathematical, to the advantage of one's physical conception of the problem. I refer to that part leading up to equation (34) which is the algebraic statement of the validity of the ordinary method of measuring three-phase power by means of two wattmeters.

Since in any three-wire system the algebraic sum at any instant of the three currents counted positive in the same direction along the circuit is zero, one of these currents may be legitimately looked upon as the common return for the other two, since when counted positive backwards it is equal at each instant to the algebraic sum of the other two currents counted

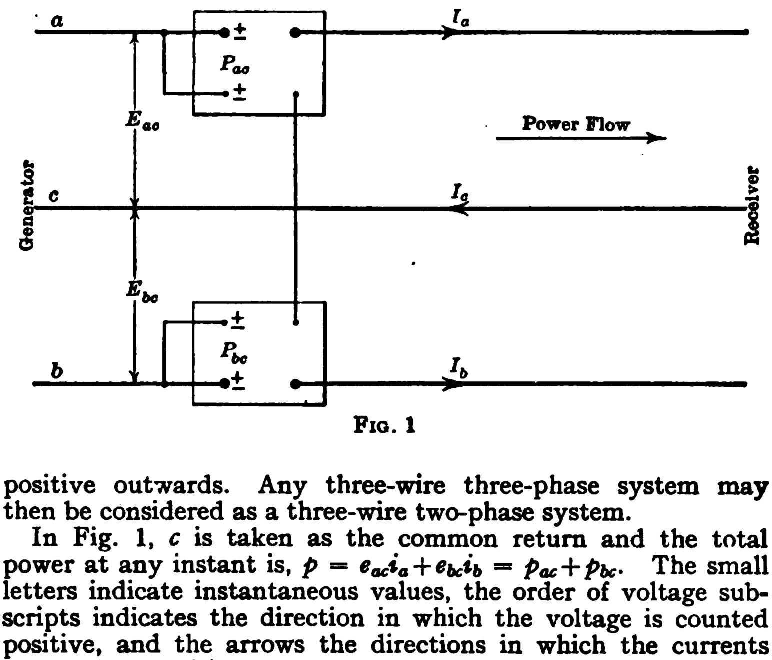


Fig. 1

positive outwards. Any three-wire three-phase system may then be considered as a three-wire two-phase system.

In Fig. 1, c is taken as the common return and the total power at any instant is, $p = e_{ac}i_a + e_{bc}i_b = p_{ac} + p_{bc}$. The small letters indicate instantaneous values, the order of voltage subscripts indicates the direction in which the voltage is counted positive, and the arrows the directions in which the currents are counted positive.

What is true of the instantaneous values of the powers is true of their average values and of the readings of the wattmeters; or using Mr. Burt's notation, $P = P_{ac} + P_{bc}$. No assumption is here made as to the shape of the electromotive force or current waves. If the power flow is from left to right in both circuits, both wattmeters will give positive deflections when connected as shown. If one gives a negative deflection when so connected, it indicates a backward flow of power in that circuit and the reading of this instrument, when its pressure-coil connections have been reversed, must be subtracted from that of the other wattmeter to give the total outward flow of power.

Thus the point of view involved in this proof (if it may be dignified by that name) not only emphasizes the direction of power flow and its relation to the relative direction of current and electromotive force, but it also points out a positive method of connecting the two wattmeters into the circuit.

The proof given above is only a special statement of the more general proposition* that if in any three-wire system, (Fig. 1), the currents i_a and i_b and the simultaneous electromotive forces e_{ac} and e_{bc} are given for any instant, the system is for that instant completely determined in all its vital aspects, and that it is entirely immaterial as to how the three wires may be interconnected in the receiving apparatus, which may be two-phase, single-phase, three-phase star, three-phase delta, or a complicated network of many branches.

There should therefore be a power-factor so definable that it is wholly determined by E_{ac}, E_{bc}, I_a, I_b and their phase relations, and thus independent of the number of branches of the receiving circuit. Of such a power-factor Mr. Burt has very opportunely supplied the definition.

The proposition given above, as well as Mr. Burt's definition of power-factor, apply equally well to an n wire system of which $n-1$ line currents and $n-1$ line voltages are given.†

Frederick Bedell: As I understand Professor Adams, the explanation he has given can be made to form a rigorous proof if it is expressed in mathematical language by the method given by Professor Blondel in his paper on "Measurements of the Energy of Polyphase Currents" in the *Proceedings of the International Electrical Congress of* 1893.

H. L. Wallau: The method of measuring the power-factor of an unbalanced delta system appeals to me because in our system we use exclusively a three-phase delta, 2300-volt distribution. The main power feeders are separate three-phase feeders and are, generally speaking, balanced. However, our lighting circuits also have small amounts of power connected to them, a great many having single-phase loads in the form of small motors, mercury rectifiers, and arc lamps, together with single-phase branches supplying straight incandescent loads. For that reason our lines are to a greater or less extent unbalanced, and it has been of a great deal of importance to

* At the time of the oral discussion of this subject at Atlantic City the writer was convinced and stated that the proposition given above covered also the proof leading up to Mr. Burt's equation (35), but while the conviction remains, he has been unable to see the connection clearly enough from the physical point of view to express it in simple non-mathematical form.

† "Polyphase Power Measurement" by C. A. Adams, Electrical World Jan. 19, 1907, p 143.

us to obtain an average power-factor which would truly represent the conditions on any particular feeder.

I think that in all cases where similar systems are being used, the power-factor on the system, as a whole, can be closely approximated by obtaining power-factor on various feeders. I have used various approximations to get at the average power-factor on the sub-station, for the purpose of determining the proper size of rotary condenser to be installed, to bring the power-factor up to such a value as would give an economical transmission from the generator to the sub-station, and also under certain cases the proper size of condenser to be installed on the customers' premises, in order to bring the power-factor up, sometimes, from a value as low as fifty per cent. to what might be called a livable value, one commercially practicable.

B. A. Behrend: I think that Messrs. Adams and Bedell are correct in regard to their simple way of proving the time-honored method of measuring the power-factor and the kilowatts of a three-phase alternating-current circuit. Their method is very interesting and instructive.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 30, 1908.

SOME ENGINEERING FEATURES OF THE SOUTHERN POWER COMPANY'S SYSTEM

BY J. W. FRASER

It has been aptly stated that in order to build a hydroelectric power system there are three fundamental requirements:

1. A sufficient source of power.
2. A market for the sale of power within economical transmitting distance.
3. The necessary capital.

It is not the intention of the writer to discuss these three fundamentals in a general way, but to take a concrete example and show how the conditions governing the sale of power must affect the design of the system as exemplified in that with which he is connected, and to describe in a general manner this system proposed ultimate extension of the same.

We will assume for the purpose of this paper a sufficient source of power, as any discussion of the hydraulic conditions would lengthen this paper undesirably. In passing, attention will be called only to the location of the various sites shown on the map, Fig. 2. These aggregate not less than 150,000 h.p. One only, the Catawba plant of 10,000-h.p. capacity was partly developed. The nine others are scattered along the Catawba River for a distance of 120 miles, with one on the Broad River about 30 miles west of Catawba Station.

In discussing the market at the time when the Southern Power Company was organized (1905), attention is first called to the map, Fig. 1, showing the location of cotton mills in the South, on which is shown a rectangle covering an area of 140 miles north and south by 180 miles east and west, about equally distributed in North and South Carolina. This area

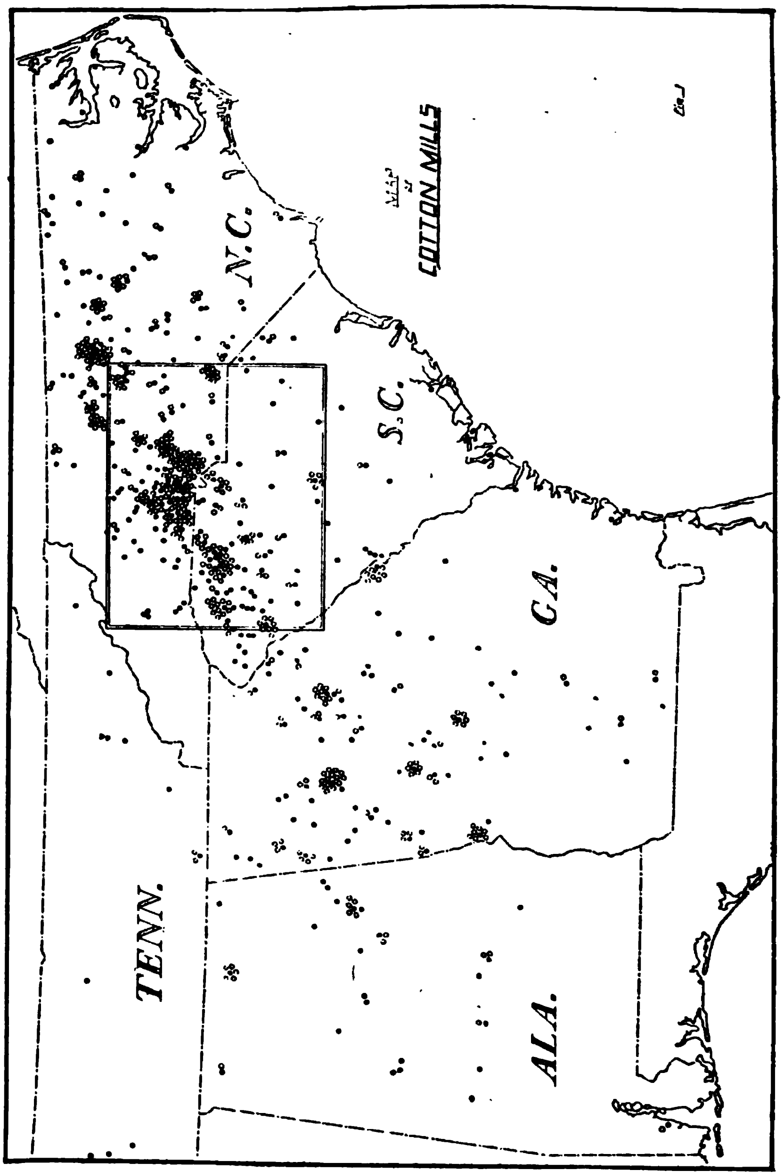


FIG. 1.—Map of cotton mills.

● Built before 1892 ○ Built between 1892 and 1907 is enlarged on the map, Fig. 2. It will be noted that it contains the largest number of mills that can be taken in by any such area in the South. It represents a power consumption of approximately 200,000 h.p., one-fourth of which is water power. It is all within easy transmitting distance from the various power sites referred to in the above paragraph.

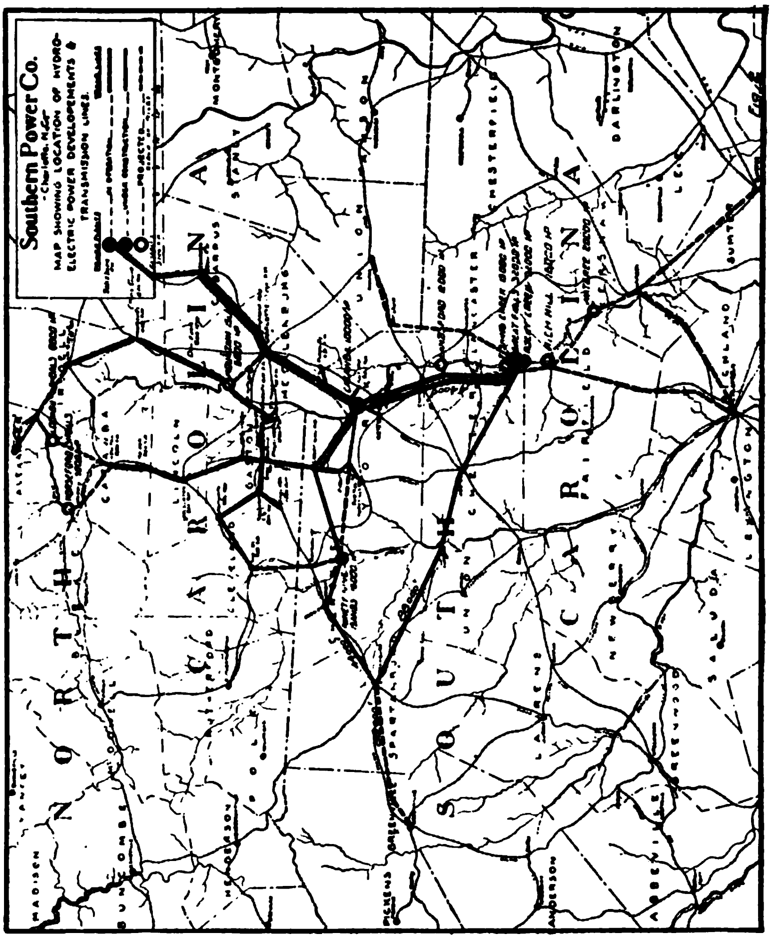


FIG. 2.—Map of Southern Power Company's transmission lines.

Before investing in these sites a careful investigation showed the average cost of power to be in the neighborhood of $34 per brake h.p. year of 3366 hours; that, although a few of the larger mills had got this cost down to $30, the majority of the smaller mills could not produce power for much less than $40. With

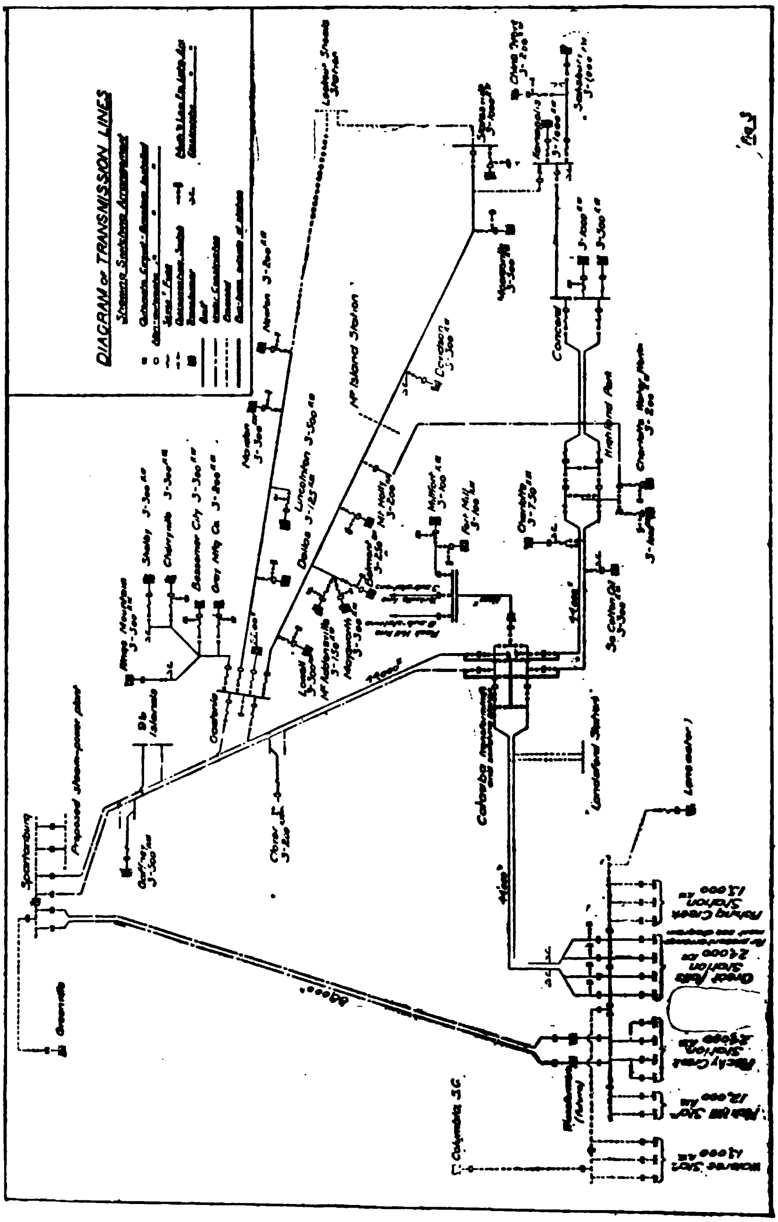


FIG. 3.—Transmission lines and switching arrangements.

coal at $3.50, power could not be distributed for less than $28, even from large central steam stations. Experience acquired from the Catawba station and some smaller stations, to the records of which access was had, showed a fair margin of safety after transmission and other losses were taken into account.

True it is that in recommending investment in these sites it had to be considered that although the electric drive had demonstrated in some instances its reliability, convenience, and economy, yet the unsatisfactory history in other instances, the general impression that power was produced for much less than it actually cost, and the fact that mill owners were averse to further investment, would make the sale of power a difficult matter. Still the main question which interested the investor was the cost of steam power, for prejudice could be overcome and the real cost of power could be demonstrated. In a further discussion of the market, it is found convenient to treat of it under separate heads embodying the various engineering features.

Frequency. In determining what frequency would best suit the market conditions the following had to be taken into consideration:

a. That the 60-cycle generators at Catawba station and some 8000 to 10,000 h.p. in induction motors receiving power from that station would have to be rewound or exchanged, if other than 60-cycle were used, on account of the fact that separate lines would be too expensive and would complicate matters. Motor-generators would make the cost prohibitive, because of the large number of distributing points.

b. That 60-cycle motors to a total of approximately 8000 h.p. were driving mills in the vicinity of proposed lines, which load might be obtained, provided the frequency were the same.

c. That there were also quite a few small city plants operating at 60 cycles. At present this might not amount to much, but the growth of these cities had to be considered, particularly in reference to arc lighting. In three years 2500 arc lights have been put in service, and if motor-generators had had to be installed the cost to small mill towns would have been excessive.

d. That a high frequency would give a better power-factor, due to the leading charging current.

e. That 25-cycle generators, transformers, and motors would cost at least 10%, 25%, and 10%, respectively, more than 60-cycle generators, transformers, and motors.

f. That there was very little prospect in the near future of a synchronous converter or railway load, and there were plenty of cotton mills in the district covered to use all the power which could be generated from the rivers.

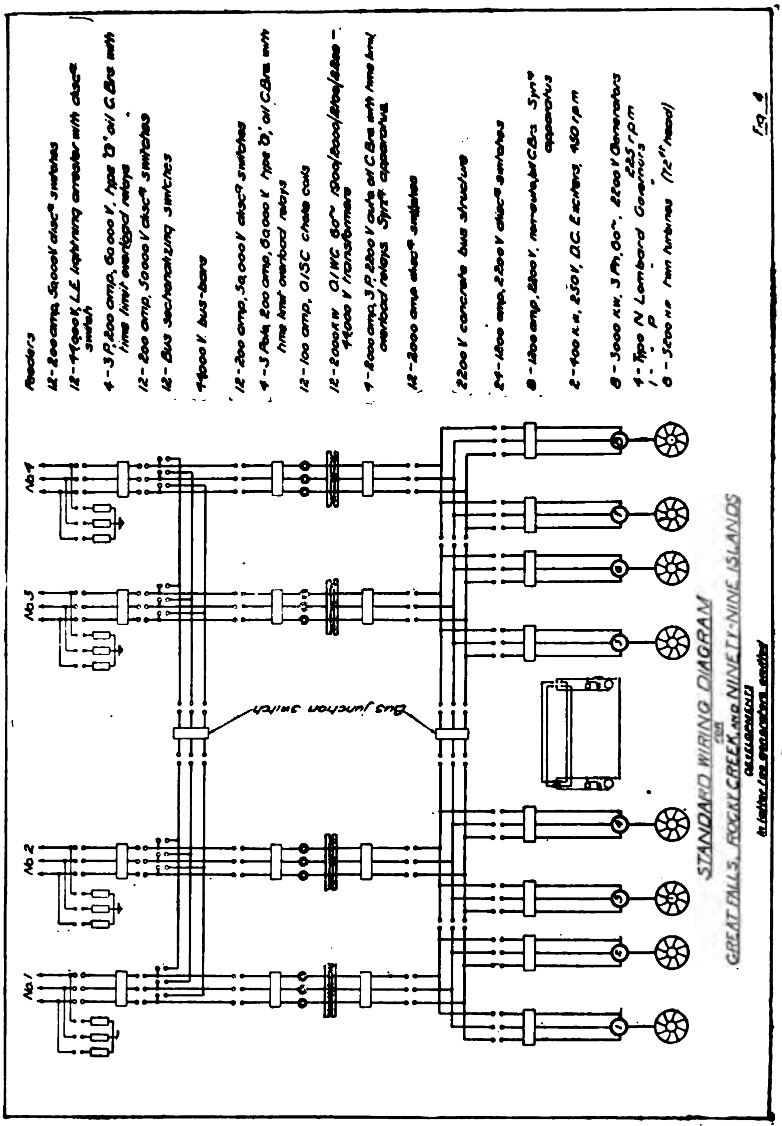


FIG. 4.—Type of station wiring diagram.

Against the above is the extra line-drop, but when all the developments are completed very little power will be transmitted more than 40 miles, except over trunk-lines where the drop may be taken care of by raising the generator electromotive force. For instance, the voltage at Catawba and at Spartanburg, two centers of distribution, can always be maintained at 44,000 volts.

These considerations seemed to favor 60 cycles, but as exact figures were necessary in this case the following rough calculation was made: the saving in cost of generators and transform-

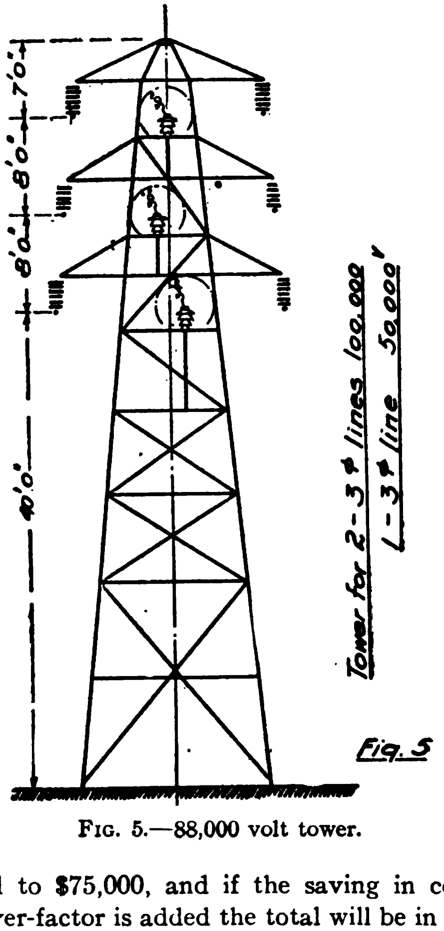


FIG. 5.—88,000 volt tower.

ers amounted to $75,000, and if the saving in copper due to increased power-factor is added the total will be in the neighborhood of $100,000.

There is an additional loss of about 10% of the loss which there would have been at 25 cycles, and the integrated loss over the present lines when fully loaded will be in the neighborhood of 27%. In power this amounts to 10% of 27% of 26,000 kw. =

700 kw., which at \$5.00 per kw. is \$3500.00. Capitalized at 6%, this amounts to \$60,000—a balance of \$40,000 in favor of 60 cycles. It is possible that a very careful analysis might show this loss to be a little greater, but the error cannot be over 25% as the integrated loss referred to has been taken over a period of six months and covers losses from generators to meters on load. The only other error which could be made would be in estimating the line-drop when the present lines were fully loaded, but as the drop on the present load has been measured the error could not be very large.

Considerations (*a*), (*b*), and (*c*) have been left out of the above numerical calculation but might easily amount to several times the figure mentioned.

Voltage. Some of the reasons for keeping the electromotive force as low as 44,000 volts were:

a. That 44,000-volt transformers would cost from 18% to 33%, depending on the size, less than for 66,000-volt transformers.

b. That transformers and switches are more reliable at 44,000 volts.

c That insulators would cost about 80 cents less each.

d. That line operation would be more successful.

e That smaller transformer stations could be built.

It was estimated that the extra copper to give the same drop over the entire system at 44,000 volts as compared with 66,000 volts would not exceed the extra cost of transformers, insulators, sub-stations, switches, and other apparatus. The estimate proved correct. With the present 30,000-h.p. load there are on the system 72,000 kw. in step-up and step-down transformers; the additional cost if 66,000-volt transformers had been used would have been

	\$64,000
Additional cost of 30,000 insulators at 80¢..........	24,000
" " " 30 66,000-volt sub-stations, *i.e.* 20% of \$125,000....................	25,000
" " " step-up transformer stations, *i.e* 10% of \$200,000................	20,000
	\$133,000

Against this is the saving in copper in the transmission line had the higher e.m.f. been used, roughly 50%..\$130,000

This shows a saving of only \$3000 but the present lines will carry a great deal more power than they are now carrying, which will increase this amount materially.

One line only of those proposed stands out as an exception, the trunk line running from Great Falls to Spartanburg and thence to Greenville, about 100 miles in length. This line now under construction will be so built that when overloaded at 44,000 volts delivered electromotive force it can be changed to 88,000 volts (*i.e.* 100,000 volts at generating station). This will be accomplished at a very small additional expense by mounting pins and insulators similar to those now used on our wood-pole lines on the towers as shown in diagram, Fig. 5, for after conversion to a higher electromotive force these pins and insulators can be used on

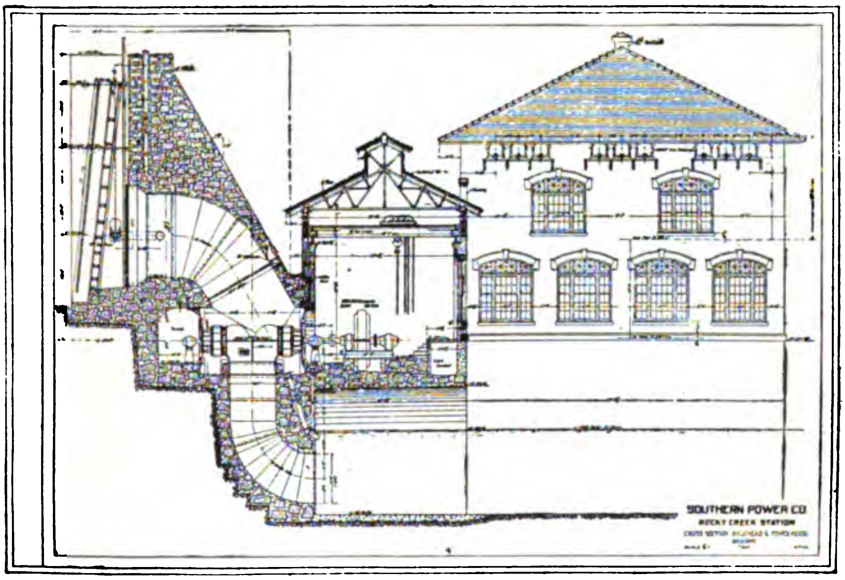


FIG. 6.—Section of Rocky Creek power house showing racks, gates, intake and tunnel for inner turbine bearing

44,000-volt lines, or this line may be permanently used for local distribution. The intention is that this 88,000-volt trunk-line will not be tapped at any point except at Spartanburg. This could be done more easily by using 100,000-volt suspension-type insulators, but it is felt that by the time it is necessary to change to the higher electromotive force there may be enough improvement made in these insulators to warrant the extra expense which would be incurred.

Transmission lines. Further examination of the transmission-line map will show that two-thirds of the obtainable power is in the neighborhood of the Great Falls development. This position was selected as a main switching station, the idea being to mass the output of Great Falls, Fishing Creek,

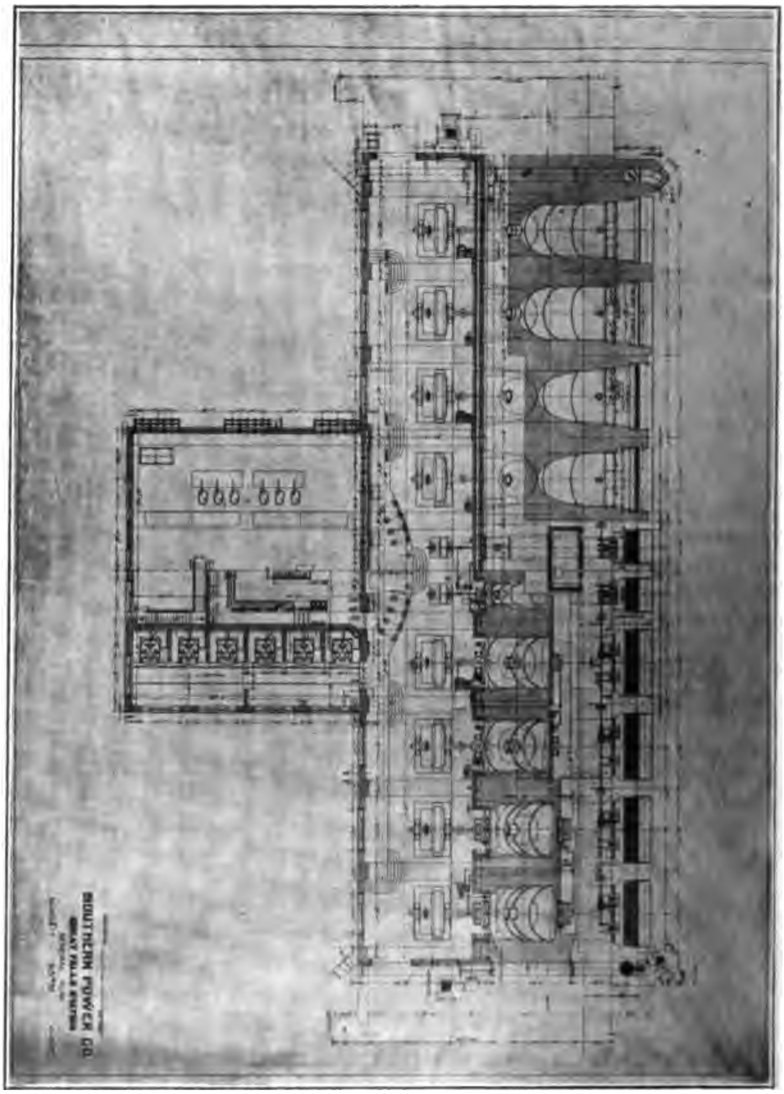


FIG. 7.—Plan Great Falls and Rocky Creek stations showing arrangement of generators, transformers high- and low-tension switches

Rocky Creek, and Rich Hill at this point on outdoor bus-bars and control the line switches from the operating room in this station.

Fig. 8.—Outside view Great Falls station showing bulkhead wall and transformer house with line openings

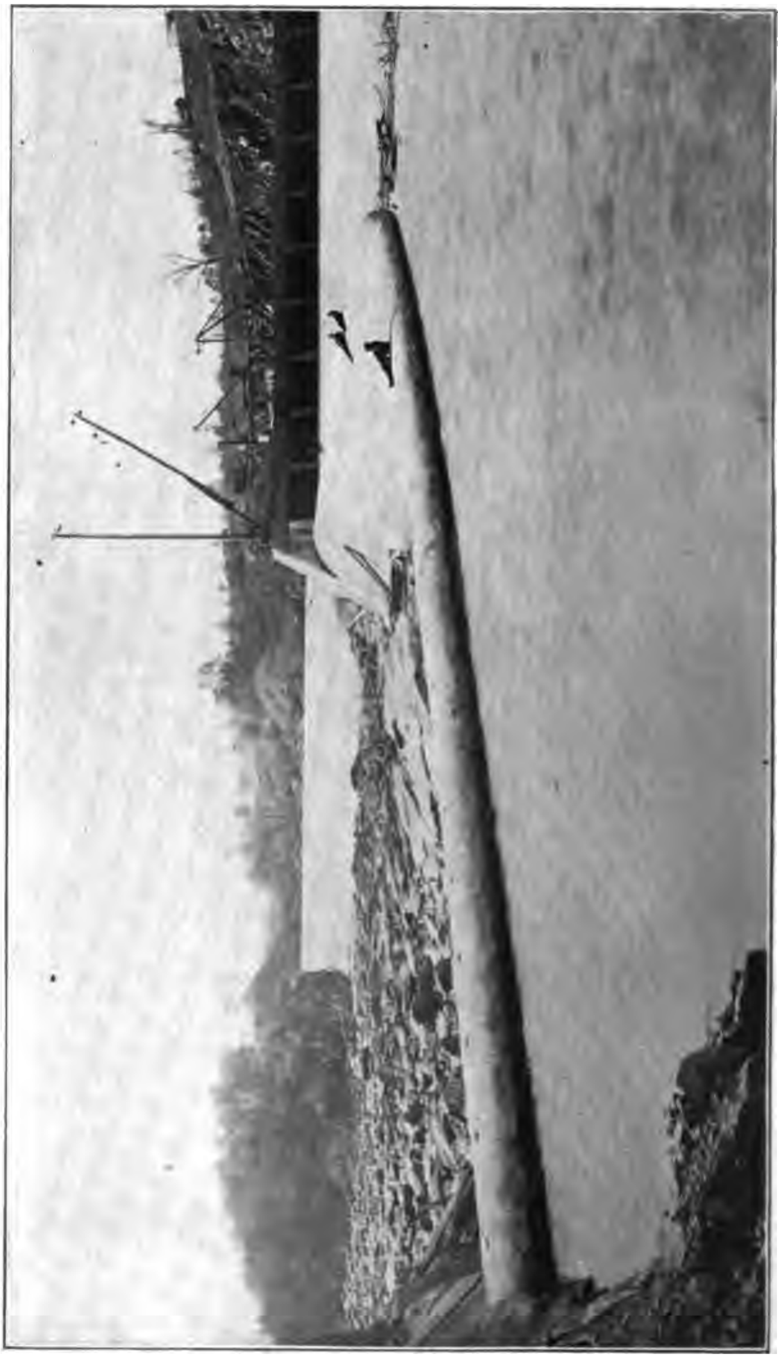


FIG. 9.—Great Falls dam, showing racks, head gates and method used to obtain long spillway

The generators and transformers were designed to operate continuously at 85% power-factor to take care of an induction motor load, and at 115% normal electromotive force to take care of line-drop as the load increased. The main trunk line, from Great Falls to Catawba Station will take care of 20,000 kw. at 85% power-factor, with a line-drop of 13.5% and a loss of 7.25%. This represents the economical section of copper at 20 cents per pound with power costing $5 per kilowatt-year.

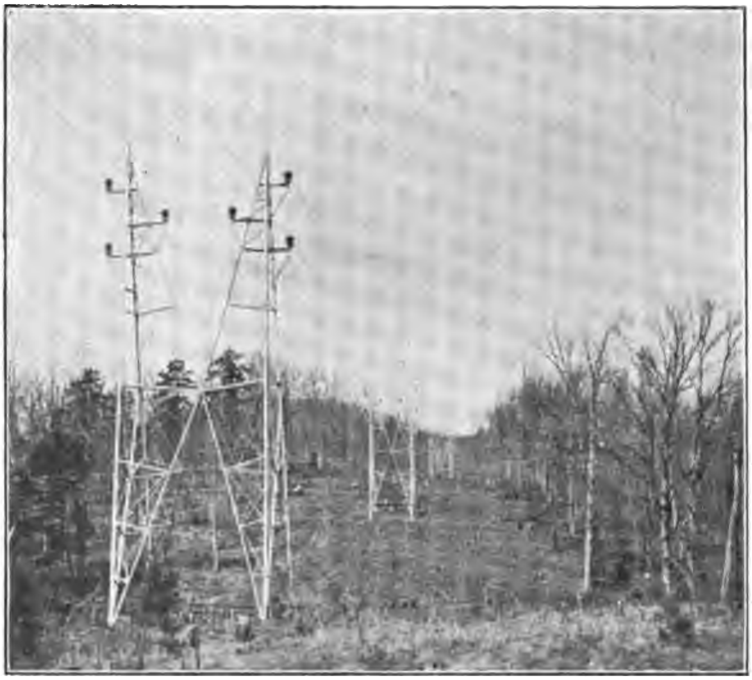


FIG. 10.—Main line steel tower.

It should be pointed out before leaving the subject of transmission lines, that the impossibility of making contracts with mill owners on account of their skepticism with regard to the electric drive, before the greater part of the present lines was actually built, made estimates on the amount of power to be sold in any one territory so difficult that the location and size of transmission lines could not be determined even approximately. In other words, where and in what amounts power was to be sold was a very uncertain matter.

This brought up the question of wood-pole lines versus steel towers. A little consideration showed that if the cost of towers per additional foot in height erected were $7.00 and copper were at 20 cents per pound, a No. 0 B. & S. gauge would be the smallest wire which could be strung economically on account of the increased sag in wires below this size for 500-ft. spans; that a single-circuit tower line would cost approximately twice as

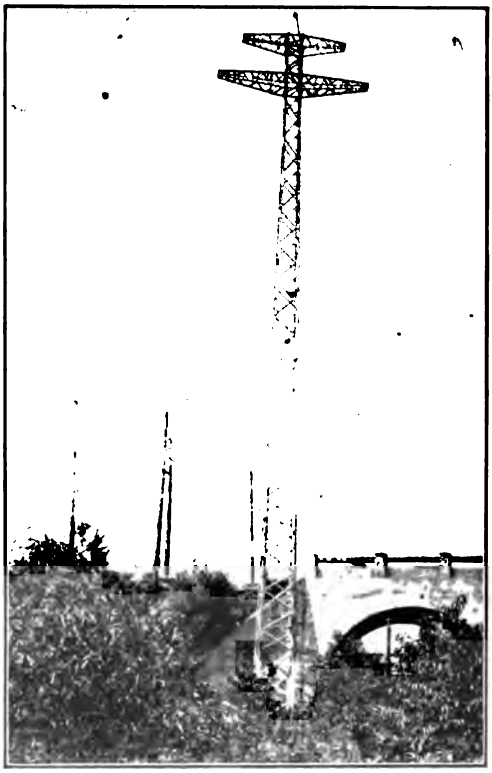


Fig. 11.—Steel pole used for city work

much as a pole line and would last probably twice as long; that a double-circuit tower line would cost very little more than a double-pole line; and that it would be more economical for cotton mills to shut down for a small percentage of time than to pay the additional price for power which would be necessary to cover the extra expenditure for steel tower lines. It therefore seemed good practice to build main trunk-lines of steel towers and all single lines below No. 0 gauge of wood poles.

Still another factor increased this difficulty. One large development under construction and several others recently financed by competing companies tended to make mill owners hold off for better prices. I refer to this merely to show how such a matter may affect the design. Considerable discussion resulted as to whether Great Falls and Rocky Creek should not be made into one development by means of a canal and pipe lines. This would take at least as long again as to develop one source and would cost the same as separate developments. Decision was made for separate developments on account of the quicker delivery of power.

Sub-stations. The first motor installations in cotton mills on this system were of 550 volts, but it was soon seen that the number of small transformer sub-stations, besides complicating operation, would cost excessively, and after some investigation 2000-volt motors were recommended for all mills converting from steam to electric drive. These installations proved so successful that to-day over one-half the total horse power in motors is at 2000 volts. The cost of the conduit in the mills for 2000 volts is nearly offset by the smaller wire used, and this electromotive force permits all mills within a radius of two miles to be fed from one sub-station. Many new mills, on account of using individual drive and consequently motors below 30 h.p., are compelled to step-down at least a part of this current to 550 volts.

The sizes of transformers in sub-stations are as follows:

11,000 volts (All purchased before beginning of new development)			44,000 volts		
5	Stations with	3–100 kw.	1	Stations with	2– 100 kw.
5	" "	3–125 "	1	" "	3– 125 "
3	" "	3–150 "	1	" "	3– 150 "
1	" "	3–200 "	7	" "	3– 200 "
1	" "	3–250 "	8	" "	3– 300 "
1	" "	3–500 "	5	" "	3– 500 "
			1	" "	3– 750 "
			4	" "	3–1000 "
		7,575 kw.			34,175 kw.

Many of the 44,000-volt sub-stations below 900 kw. are now partly or wholly owned by customers, as are also some of the

900-kw. and 1500-kw. stations, most of the mills in one town preferring to take shares rather than pay the additional price for power necessary when the station is owned by the power company. The customer usually requests that the power company buy and install the sub-station apparatus. The customer gets the benefit of any experience which the power company may have and obtains sub-stations at a minimum cost. In the larger towns where attendants must be kept it has been found more satisfactory for the company to own the sub-station. The power company has discountenanced the buying of trans-

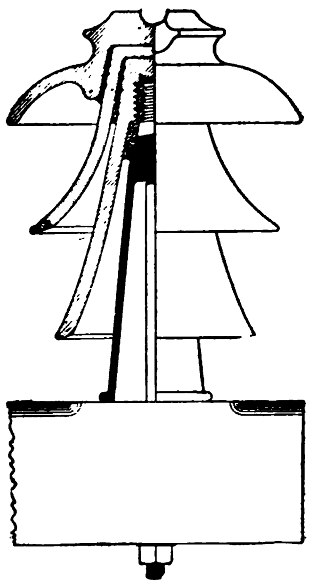


FIG. 12.—44,000 volt insulator.

formers below 200 kw. on account of the high cost of completed stations per kilowatt. In the case of a 900-kw. station (3-300-kw. transformers) when the transformer cost is two-thirds of the total and 150-kw. cost 50% more per kilowatt than 300-kw. transformers, the power company has taken a share in the station rather than have the customer install the small transformers. The companies consider this to be to their interest in view of the facts that they get all new mills and that the interest on the additional investment for two years would not pay the installation charges for substituting the large transformers when they were needed.

All sub-station transformers have been purchased under a standard specification in order that a few stock transformers which the power company has made it a policy always to keep on hand may serve as spare apparatus in case of accident.

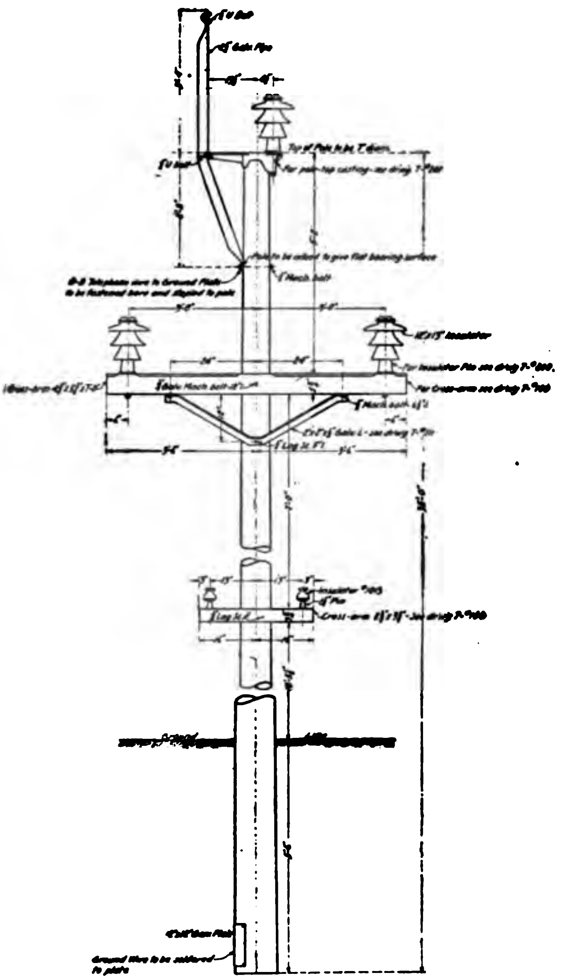


Fig. 13.—Standard wood pole

It is believed that no transformers below 300 kw. and very few below 500 kw. will have to be purchased in the future; for with the present rapid growth of cotton mills and the use of 2200-volt distribution in the towns where sub-stations are located, the small transformers will have to be exchanged for larger ones, the smaller ones being available for the new sub-stations carrying small loads.

It may be of interest to some to know that there are now on

FIG. 14.—Type of sub-station

our lines 114 50,000-volt fuses of the expulsion type and that they have proved entirely satisfactory.

Secondary power. From government records and from six years of gaugings before the completion of the Catawba plant,

FIG. 15.—Type of sub-station

together with two years' operating experience, the flow of the Catawba river had been pretty well determined. The question which presented itself most forcibly was whether to develop the average minimum 12 months' flow, or to develop for 10 months, 8 months, or less, and to supplement with steam power—a problem which has to be determined by the first cost of development and by local market conditions.

Owing to limited library facilities at his command, the writer was unable to ascertain if this question had been touched upon

FIG. 16.—Type of sub-station

elsewhere and how in other cases it had been determined, and so trusts that a few words with reference to this particular case will not be amiss.

In the following calculations where the cost of primary and

FIG. 17.—Catawba dam

secondary power is taken at a fixed rate, the intention is not to convey the idea that these are actual figures but relative figures which will serve the purpose of this paper.

There are many different solutions to the problem of ascertaining the amount of secondary power which may be economically developed. At one of our developments it was found that the average minimum primary power was in the neighborhood of 16,000 kw. and that the increase per month of secondary power was in the neighborhood of 12.5%; *i.e.*, 2000 kw. per month. In other words, if secondary power were to be developed for 8 months' sale, the total development of primary and secondary power would be 24,000 kw. If this secondary power can be sold without an auxiliary steam plant, the amount of secondary power which may be developed economically depends only upon whether or not the price received for such power will cover interest and profit on the investment; that is, the investment

Fig. 18

which is over and above that for developing primary power: but if a steam plant has to be maintained the amount of secondary power to be developed depends also on the cost of steam power. It is very clear that the cost of secondary power is practically the same, whether it is sold for 11 months or 1 month. With this cost, say at $10.00 per horse power delivered, steam at $28.00 per horse power-year ($6.00 interest and depreciation, $22 for coal, operating expenses, etc.), if interest and depreciation on the steam plant is entirely chargeable to the months when steam plant is in operation, then

$$\text{Cost of steam power per month} = 1.83 + \frac{6}{x}$$

When x = the number of months in operation.

Amount of secondary power to be developed = 16,000 kw. $\times \frac{12.5x}{100} = 2000x$ or $\frac{2000x}{0.746}$ h.p.

$$\text{Cost of steam + secondary} = \frac{2000x\,(1.83+\frac{6}{x})\,x + 2000x \times 10}{0.746}$$

$$= \frac{2000\ \ (1.83x^2+6x+10x)}{0.746}$$

If power is selling at \$20, profit

$$= \frac{(2000\,x\ 20- \{2000\ \ (1.83x^2+16x)\}}{0.746}$$

$$= \frac{2000\ (20x-1.83x^2-16x)}{0.746}$$

$$\text{(For max.)}\quad \frac{dy}{dx} = 3.66x-4$$

$$x = 1.1 \text{ month}$$

On this basis maximum profit would be made on 2200 kw. secondary development.

A more practical method under existing conditions seems to be to charge the interest and depreciation of steam plant to the operating expense of the system, inasmuch as the steam plant is an insurance against a partial shut-down and makes spare units unnecessary, and in the case of steam turbines, when run as synchronous motors, saves copper because it brings up the power factor. The above equation now becomes:

$$\text{Cost of steam + secondary} = \frac{2000x\,(1.83x) + 2000x \times 10)}{0.746}$$

$$= \frac{2000\ \ (1.83x^2+10x)}{0.746}$$

$$\text{Profit} = \frac{2000\,x\ 20-\ (2000\ \ (1.83x^2+10x)}{0.746}$$

$$= \frac{2000\ (20x-1.83x^2-10x}{0.746}$$

$$= \frac{2000\ (10x-1.83x^2)}{0.746}$$

$$\text{(For Max.)}\quad \frac{dy}{dx} = 3.66x-10$$

$$x = 2.75$$

Maximum profit on this basis would be made on 5500 kw. (35%) secondary development.

Had \$24.50 been taken as the selling price of power, x would equal 4 months, or the total development should be made for 150% of mean average low water. Although power from hydroelectric plants has been selling in the Carolinas for less than this latter figure there is no doubt that reliable service demands this price.

There is another argument in favor of developing for 150% mean average low water. If it costs only one-half as much to develop secondary power as primary, twice the loss can be allowed on transmission lines; or, in other words, one and one-half times the power can be transmitted during secondary power seasons. Now, if the transmission lines are figured for an economical loss when transmitting primary power only, secondary power to the extent of 50% of the primary power can be developed without additional copper. This only holds good when the auxiliary steam plants can be built in the neighborhood of distribution centers whose consumption of power is equal to the amount of secondary power.

Many mills which had steam plants already installed made contracts for secondary power for eight months in the year, but after a few months' operation by electric drive their owners found the production so much increased and their labor and other troubles so much lessened that many of them desired to change their contracts to primary power. The result of this is that the plans for a supplementary steam plant are now in course of preparation. The initial installation will be 15,000 kw. and will be located at Spartanburg, S. C., near the southern end of the system, 64 miles from the main switching station at Great Falls on the 88,000-volt line. The ultimate installation is expected to reach 40,000 kw., divided between this point and some point near the eastern end of the system. It is thought better to divide the plant for safety and in order that the line loss may be kept as low as possible.

Discussion on "Some Engineering Features of the Southern Power Company's Systems." Atlantic City, N. J., June 30, 1908.

J. H. Finney: I believe that many of us here fail to realize the actual value of the work that has been done by the Southern Power Company in the south. I think that there are not many electric plants in this country that I have not seen at one time or another, and I believe the work that has been done in developing the water-power system of the Catawba river by the Southern Power Company is as creditable as any similar work in the United States. It is well worth while to go down and see that Great Falls plant, the Rocky Creek plant, and the others there.

W. S. Lee: Perhaps a good many engineers do not know the conditions that we have to meet on southern streams. There is an erratic flow, a flood discharge on several of these plants one hundred times the minimum discharge; this means quite a problem in designing the structure from the hydraulic end, as well as trying to apportion the station equipment so as to use the secondary power to the best advantage. We have studied this condition carefully, and while we have adopted the plan of putting in station equipment about one and one-half times the minimum low-water requirements, naturally there is a possibility of even changing that, due to the fact that a great many southern cotton mills have efficient, large steam plants. We are now offering power for sale on a six months' basis, which we call six months' secondary power, at a much lower price. This six months' power is an inducement to the large plants, which can run six months on steam and six months on water power. In some years the water flow is a little greater, and the mills can then be operated by water power eight months, or even ten months, and on rare occasions, twelve months in the year.

We first had a great many 550-volt motors on the cotton-mill work, and were endeavoring to make the voltages multiples. We saw at once that in cotton-mill work it was not advisable to install a 44,000-volt sub-station for each mill, consequently almost all installations are now using 2200-volt motors. We have towns in which we operate seven or eight mills from 200 to 500 h.p. each, where it is possible to locate one sub-station. All our transformers are wound for 550 and 2200 volts on the low-tension side, and 11,000, 22,000, and 44,000 volts on the high-tension side.

Reference to the map will show the location of the Great Falls station, Rocky Creek station, and Fishing Creek station. Great Falls station being between the other two, it is our intention to feed Rocky Creek and Fishing Creek stations into a common switch house or bus-bars, which will be located at the Great Falls station. This will enable the attendants at Great

Falls station to control all lines or feeder circuits. We are also designing an 88,000-volt transmission line from Great Falls to Spartanburg, S. C. The transformers and control of lines for this voltage will also be handled by attendants at Great Falls station.

D. B. Rushmore: The plant of the Southern Power Company is one of considerable interest. The voltage of the plant, 44,000, was the maximum conservative voltage at the time of installation. At present one would use a higher potential for such conditions. Efforts should be made to standardize transmission voltages. Below 44,000, the figures are fairly well fixed; above, there exists a wide variety of voltages. We must either decide on delta-star combinations, or else choose some arbitrary figure. For high-voltage transmission work one does not change the system of connections from delta to star after the first decision has been made; therefore an arbitrary decision on multiples of eleven seems the most logical basis. The following voltages are recommended for transmission work: 6600, 11,000, 22,000, 33,000, 44,000, 66,000, 88,000, 110,000, and 165,000; 66,000 is already in operation in so many places that it already has an existence; 88,000 is taken as the double of 44,000. On transmission lines it is often desirable to double the voltage and to wind transformers for the higher voltage, using them for parallel connection on the lower voltage. A large number of plants are now being installed at or about 100,000 volts. It seems desirable to fix this figure at 110,000, these voltages being the voltages at the generating station. 165,000 is proposed for the next step.

One of the factors which has entered into the successful operation of this plant has been the use of 60,000-volt insulators on the 44,000-volt line. The greater margin of safety is one of the results of experience in this line of work.

It is to be noted that this system employs a delta connection on the transformers on the high-voltage side; also that a compromise is effected concerning the use of transformer compartments, and that the high-tension wiring is entirely open.

A feature of especial interest is the use of expulsion fuses instead of automatic switches for protecting the sub-station apparatus. It is understood that this feature has been very satisfactory.

P. M. Lincoln: I agree with Mr. Rushmore that it is desirable, if possible, to fix high-tension voltages in advance of their use, but I am not sure that it is best to eliminate the 88,000 volts. There are a number of plants in which this voltage is proposed; the reason for it is that the plants are to go in at first at half that voltage, 44,000 volts, while the amount of power called for is small, but they are being installed with the intention of eventually doubling this voltage. The fact that there are two different but obvious methods by which transmission voltages may be increased is responsible for the existence of the odd voltages.

Voltages may be increased either by doubling the previous voltage or by throwing delta-connected transformers into a star connection. In the former case the factor of increase is two and in the latter $\sqrt{3}$. With this constant tendency toward odd transmission voltages the adoption of standards becomes all the more important.

In regard to the question of delta- versus star-connected transformers, I think that the selection of delta or star connection depends largely upon whether the neutral of the high potential system is to be grounded or not. If the grounded neutral is to be used, the star connection of the high-tension side is essential to obtain a neutral point. If the grounded system is not to be used, there is not much choice between the delta and the star. It is true that the star-connected transformers are somewhat less in cost than a similar set of delta-connected transformers, but this is not a controlling advantage. The whole thing hinges upon the larger question of whether the high-tension transmission system is to have a grounded neutral or not.

Chas. P. Steinmetz: I desire to commend the engineers who have designed this plant, on their conservative way of choosing transmission voltages and transmission design, which ought to go a long way to maintain the record of reliability of operation acquired by the smaller station, of which this big system is the successor. Many of us do not realize the enormous work which is being carried on in the electrical development of the South. We read, and have heard, for many years of the long-distance transmissions in the West and Central states. Great results have indeed been accomplished there, where coal is almost out of the question by reason of its price, and where the distances are long and the voltages high, but not all of us realize that similar development is going on in the South. The development may not be of greater magnitude, but it is under different conditions, in competition with steam. The southern plants do not supply mines and towns which do not mind an interruption once in a while; they supply consumers like city lighting plants or cotton mills, where it is a serious matter to shut down and throw hundreds, if not thousands of hands out of work. There more conservative voltages must be used, and while 100,000 volts may be all right in the West, they are a little high for the South.

It is very encouraging to see how a system of enormous magnitude, fully as large in kilowatt capacity and in extension over distances as any western system, has chosen 44,000 volts as the trunk-line voltage for transmission, using half or quarter thereof for the high-voltage distribution system, and leaving it for the future, when necessary, to use a line of double that voltage, 88,000 volts.

Fourteen years ago the first cotton mill was installed in the South with electric drive. It is hard to realize how the whole South has rapidly developed commercially, and how electric power is coming to the front. Water power systems are everywhere being developed. It is encouraging to see that this great development has been on conservative lines, and it is to be hoped, that as a result of the development of these systems, we will be able to say that long-distance transmission is as reliable as local distribution, and that it will not be necessary to say—among ourselves not to the public—that long-distance transmission is ideal where you get the power, but after all you never know whether you will get the power or not.

P. H. Thomas: I ask Mr. Fraser if he should not add to the advantages of the large secondary steam development, the extra capacity of reserve, in case of trouble?

One other question: Does the term "average minimum primary power" indicate power that could be actually developed with no steam auxiliary at all?

J. W. Fraser: Mr. Lee has answered the question as to the 44,000 volts, and higher voltage, which we expect to use, and he has also answered the question regarding the wiring diagrams. With regard to the fuses, we have something like one hundred and twenty-five 50,000-volt fuses in use, and have used them in all the sub-stations. They work very satisfactorily indeed.

Replying to Mr. Thomas's question; that is the average power obtained for a number of years without any secondary power at all which would be developed if we had no steam power.

P. H. Thomas: Will you describe the fuses more particularly?

J. W. Fraser: The enclosed fuse referred to is mounted on line insulators, which in turn are mounted on a treated board about 6 ft. long and 10 in. wide. The explosion takes place in a short metal barrel at the end of the fuse, which is 42 in. long, and is discharged through a fibre tube about 3 ft. long. The fuse is also used as a disconnecting switch.

With regard to voltage regulation, it does not matter what the voltage at the Great Falls station is, so long as the voltage at the Catawba station is maintained at 44,000. The main trunk line is not tapped between Great Falls and Catawba station, so that the voltage at the former station may be varied between 44,000 and 50,000 as the load changes.

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