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THE REFINING OF IRON AND STEEL IN INDUCTION TYPE FURNACES

BY C. F. ELWELL

ELECTRICAL FEATURES

The furnaces for the refining of steel electrically, which have passed the experimental stage, may be divided into two distinct groups, *viz.*, arc furnaces and induction furnaces.

To the former belong the Heroult, Stassano, Keller and Girod furnaces, and to the latter the Kjellin and Röchling-Rodenhauser furnaces. Of the former the Heroult furnace is perhaps the best known and most successful and as comparison always carries more weight than a description, it will be used as the representative of the arc furnaces. The electrical features may be divided up under several heads.

DISTRIBUTION OF HEATING EFFECT OF THE CURRENT

Arc Furnaces. In the Heroult furnace the current passes from one electrode through an arc to the slag, through the slag to the upper metal and thence through another arc to another electrode, and of the current which passes through the carbons only a small percentage passes through part of the metal. As the heating effect of the arc is far greater than any effect of the resistance of the charge, there must be large differences of temperature between different parts of the bath of metal even in spite of the great activity of the bath around the electrodes. This is especially the case with a deep bath of metal. It is for this reason that Girod employs a bottom electrode, thinking thus to have these differences of temperature less by passing all the current for the arcs through the bath. From figures given in Stahl and Eisen for a two-ton Girod furnace, it was computed that the resistance of the carbon electrode was 3800 times that of the bath of metal and so 3800 times more electrical energy was converted into heat in the carbon electrode than in the bath itself. From this it is seen that if the current in the bath of metal produces any considerable part of the heat of the furnace, there must be a large loss of energy in the carbon electrode. The only correction for this is to make the electrodes larger, and the working limit has already been reached. The fact is that the bath is very little heated by the passage of the current and almost all the heating in this type of furnace is done by the very localized heating of the arc. The matter of the losses of energy in the carbons will be taken up under the heading of efficiency.

Induction Furnaces. The principle of the induction furnace is already well known to you but in order to compare the Kjellin and Röchling-Rodenhauser types it will be well to repeat briefly the principle of operation and the type of construction of the Kjellin type. The furnace consists essentially of an iron core around one leg of which is wound a primary winding enclosed in a refractory case and usually cooled by means of forced draught. The annular hearth surrounds this primary coil and is separated from it by means of refractory material. This hearth contains the metal and acts as a secondary winding of one turn. The voltage induced in this turn is quite small so that the energy transformed from the primary coil results in a very large current in the secondary, which heats the metal and thus nearly all the electrical energy is converted into heat in the metal to be melted. The ring being of constant cross section, the heating is about uniform over the whole bath of metal. The Röchling-Rodenhauser furnace has a differently shaped hearth to the Kjellin furnace and a description would not be out of place at this juncture. The furnaces are constructed either for single- or three-phase current. In the former case there are two grooves and in the latter, three grooves. In both cases these grooves, which are similar to the grooves in the Kjellin furnace, open into a distinct open hearth. The cross section of the grooves is comparatively small and they form the secondary circuits in which the currents which heat the metal are induced. Lateral doors are provided so that the contents of the working chamber may be watched, slag drawn off or charge put in. The chief electrical difference between the Röchling-Rodenhauser and Kjellin furnace is that a distinct secondary winding is provided in the former and the current induced is led by means of heavy terminals to plates embedded in the refractory material of the furnace. This refractory material becomes an electrical conductor at the higher temperatures, and this enables an additional circuit to be formed, so that the currents induced in the secondary winding pass through the bath of metal, heating the bath still further. The current also serves to neutralize the great self-induction of the secondary and a better power factor is obtained. The point to be recognized here is that the heating is uniform and not localized as in the Heroult furnace.

VARIATION OF LOAD ON SUPPLY MAINS

Arc Furnace. The instability of an arc is well known and the load on a supply circuit, even with constant watching, varies very greatly. If the furnace has its own generator the regulation can be effected more simply but the best furnace is one which can be connected to regular three-phase supply mains. To do so with the Heroult furnace means motor-driven electrode regulators, etc., and even then the furnace is not a very desirable load.

Induction Furnaces. The changes in load on an induction furnace are always of the intentional kind and sudden changes of load are practically impossible with an induction furnace.

ADAPTABILITY TO CONNECTION TO SUPPLY MAINS

In the question of power factor the Heroult furnace shows some advantage over the Kjellin furnace for in order to build a Kjellin furnace of eight-ton capacity and keep the power factor up to 0.6 or 0.7 it was necessary to lower the frequency to five periods per second. As a five-cycle generator costs more than twice as much as a 25-cycle generator this is a serious question. But with the Röchling-Rodenhauser furnace the current in the second secondary winding can be used to neutralize the effect of self induction to such an extent that a seven-ton furnace may be operated with 25 cycles with a power factor of 0.6 while a three-ton furnace on 25 cycles has a power factor of 0.8. The smaller Röchling-Rodenhauser furnaces are operated from 50 cycles with power factors of 0.85 and 0.8. In my opinion the most economical way to correct this evil is by using fixed condensers which cost only a small percentage of the cost of the furnace and the power factor may be made as high as desired.

ELECTRICAL EFFICIENCY

Arc Furnaces. The before mentioned Girod furnace with but one electrode of 14 in. (35.5 cm.) diameter and a current of 6200 amperes at 60 volts showed a power loss of 10 per cent in the electrode alone. In the Heroult furnace the current is in general smaller but there are two electrodes in series and the result is about the same. Not only is energy lost in the electrodes by reason of their high resistance but a large amount is also lost by means of the water cooling of the jackets which is necessary because of their high conductivity for heat. The cost of maintenance of carbon electrodes is also considerable. Radiation loss is greater with the arc furnaces because a great deal of the heat of the arc is reflected to the roof which must be water cooled to last, and even then has to be renewed about every 14 days.

Induction Furnaces. Tests made on a 3.5 ton furnace at Volklingen have shown an electrical efficiency of 97 per cent which is a contrast to the 10 per cent lost in electrodes alone in arc furnaces. The electrode plates never wear out for they do not come in contact with the molten metal or slag and the portion of the lining which acts as a conductor has been found in practice to last longer than any other portion of the lining.

SUMMARY OF ELECTRICAL FEATURES

a. Heating of metal bath is much more uniform in induction furnace.

b. The variation of load is much less with the induction furnace.

c. The adaptability to connection to existing power networks is in favor of the induction furnace.

d. The efficiency is in favor of the induction furnace.

METALLURGICAL FEATURES

The earlier induction furnaces, *i.e.*, those of the Kjellin type did not show many metallurgical advantages except that it was possible to treat much larger charges than with crucible methods. They were quite unsuited to working with slag because of the shape of the hearth and so only served to melt pure materials. The shape of the Röchling-Rodenhauser furnace is such that slags can readily be handled and refining carried on. At the same time it can be used for smelting work whenever necessary, and as much larger charges can be worked, a considerable saving is made in crucible steel working.

The advantages of the electric furnace are:

1. On account of the convenient regulation of the temperature attainable the phosphorus can be removed until only a trace remains.
2. It is especially suitable for the most thorough desulphurization.
3. When the refining is complete, the charge can be left in the furnace as long as may be desired without change of composition.

At Trollhattan, Sweden, the furnace is started by means of a ring of metal. The cold materials are charged gradually until all are melted. Continuous operation is possible by leaving a portion of the molten metal in the furnace after each teeming.

At Volklingen, Germany, the furnaces are supplied with molten metal from basic Bessemer converters which contains about 0.08 per cent *S* and 0.08 per cent P. The extent of the dephosphorization and desulphurization depends on what the steel is wanted for.

An oxidizing slag is formed from lime and millscale or ore, which is removed as far as possible when dephosphorization is complete. The re-carburization takes place and a slag free from iron is formed for desulphurization. A typical slag for desulphurization has a well-known white appearance and falls to a white powder on exposure to the air. When the slag has this property, the charge may be left as long as desired in the furnace. The furnaces are entirely emptied after each charge as the molten converter steel allows the load to be readily brought to a satisfactory figure.

When not working, about one third of the normal energy will keep the furnace hot. The seven-ton furnace at Volklingen has been 30 hours without taking any current and was heated up again with normal energy consumption. Within half an hour the metal began to glow and regained its normal temperature after four hours and the charge was finished up in the regular way. At the works at Volklingen no work is done on Sunday but there is no difficulty in starting up the furnaces with unfinished charges from the previous Saturday.

The natural circulation which takes place in induction furnaces serves to thoroughly mix the charge and the management of the Poldihütte, Austria, made a test in which seven samples were taken from six different places in the furnace and the analysis of these samples is shown in the following table:

	Carbon Per cent	Manganese Per cent	Silicon Per cent	Phosphorus Per cent	Sulphur Per cent	Chromium Per cent
1	0.81	0.27	0.335	0.031	0.007	1.00 1.01
2	0.77	0.25	0.340	0.030	0.008	1.00 1.01
3	0.85	0.28	0.345	0.029	0.007	1.00 1.01
4	0.82	0.27	0.335	0.030	0.009	0.98 0.99
5	0.78	0.25	0.335	0.030	0.009	0.99 0.96
6	0.78	0.27	0.419	0.031	0.010	0.99
7	0.79	0.28	0.326	0.030	0.009	0.98

The furnace was teemed 37 minutes later and a sample cast out of the ladle gave the following analysis:

Carbon	0.77 per cent
Manganese	0.29 "
Silicon	0.396 "
Phosphorus	0.031 "
Sulphur	0.009 "
Chromium	0.99 "

That the Röchling-Rodenhauser furnace is no longer an experiment is shown by the fact that the 3.5-ton furnace was worked for a whole year producing steel for rails, and more than 5,000 tons have been sold. The eight-ton furnace has been running since November, 1908, an average of 14 days to a lining and 1,200 tons of rails to a lining. The management contemplates the building of a 16-ton furnace as the next step.

At Dommeldingen the two-ton furnace is used to refine crude pig iron.

	Analysis of charge	Analysis of cast
Carbon	4.0 per cent	0.5 per cent
Phosphorus	1.8 "	0.025 "
Sulphur	0.2 "	0.03 "
Manganese	0.0 "	0.76 "
Silicon	1.05 "	0.056 "

Breaking strain	95,000 lb. per sq. in.
Elongation	20 per cent
Contraction of area	36.33 "
Duration of conversion	5 hours.

SUMMARY OF METALLURGICAL FEATURES

1. Having no electrodes, facilities are provided for heating the bath without introducing impurities and the charge may be left indefinitely in the Röchling-Rodenhauser furnace without change.

2. Having a large open hearth, (in the 1.5-ton furnace it is 60 by 26 in. or 1.52 by 0.65 m.) with doors it is possible to do any class of refining in the Röchling-Rodenhauser furnace much the same as in the open hearth furnace.

3. When the hearth doors are closed the Röchling-Rodenhauser furnace is air-tight and may be left for long periods without great loss of heat, making intermittent working possible.

4. The natural gentle movement of the charge allows of complete mixing of the ingredients of the charge, and is not sufficient to attack the lining.

COSTS

Royalty. The German users of the induction furnace pay $0.65 per ton for rail steel and $1.50 per ton for crucible quality steel. This is for small daily production. For 1000 tons daily the royalty is placed at $0.36 per ton for rail steel and for 1200 tons daily it is $0.50 for crucible quality steel.

Energy Required. A great many figures have been given out most of which were for small furnaces and special runs. The plants at Trollhattan and Volklingen being in commercial operation supply the most reliable figures obtainable.

Cold Pig and Scrap. With cold materials, refining, etc., to crucible quality steel is done with 600 to 900 kw-hr. per ton according to the size of the furnace.

Hot Pig and Scrap. With hot pig iron and cold scrap crucible quality steel is obtained with 300 to 700 kw-hr. per ton according to the proportions of the two ingredients and the size of the furnace.

Hot Metal from the Converter. Converter material with an analysis of P, 0.08 per cent; S, 0.08 per cent; Mn, 0.5 per cent; C, 0.1 per cent is refined to steel for rails with an analysis of P, 0.05 per cent; S, 0.04 per cent; Mn, 0.85 per cent; C, 0.5 per cent with 100 kw-hr. per ton in a seven ton furnace. Same material is refined to high quality steel showing only traces of P and S; Mn, 0.2 per cent; C, 0.5 per cent with 250 kw-hr. per ton.

Hot Metal from Open Hearth Furnace. Material from open hearth furnace, already dephosphorized and desulphurized and containing 1.22 per cent C; Mn, 0.38 per cent; Si, 0.21 per cent to high quality steel with 200 to 250 kw-hr. per ton.

Cost of Production. (1) *For a 1.5-ton furnace melting scrap and refining to pour best steel for steel castings. Furnace of the three-phase, tilting type. 50 cycles, 210 kw. and power factor 0.80.*

Interest Charges. Cost with all accessories about $9,000. With 10 per cent for interest charges gives $900 annually. Using 290 working days in a year and six charges, 3 to 3.5 hours each, daily and 1500 lb. to a charge gives 4.2 tons daily and 1,220 tons yearly. This is equivalent to about 21 hours working. Cost per ton for interest, $0.74.

Labor. Two men can attend to this furnace with ease, as the electrical part requires no special attention. The melter adjusts the temperature and watches the metallurgical process. The helper sees to the fan and charging etc. Allowing two shifts and $5.50 per shift or $11 daily gives a labor cost of $2.62 per ton of steel.

Lining. Relining may be done every 8 or 14 days. It takes three tons of magnesite and 0.36 ton of tar to completely reline the furnace. The relining is done with half new material and half old. For getting out the old lining, mixing material and putting in the new, four men are allowed 16 hours. Cost of lining per ton of steel, on an average, $1.50.

If lined with dolomite, which is cheaper, and every 14 days then lining cost allowing one third material recovered is $1.00 per ton of steel.

Keeping Warm. When the furnace is not used for several hours during the night, it must be kept warm, for which about a third of the working amount of energy is necessary. In this way if normal energy is 200 kw. then about 200 kw-hr. will be necessary to keep the furnace warm over the three-hour period of rest. For six working days this is necessary five times and 1000 kw-hr. must be charged up to heating.

Cost of keeping furnace warm at $20.00 per kw-yr. is $0.09 per ton of steel.

Cooling of Transformer. The blower takes a 2.5-h.p. motor or 1.8 kw. and for 24 hours = 43 kw-hr.

Cost of cooling transformer per ton of steel, $0.02.

Energy Consumption. From cold materials about 850 to 900 kw-hr. are necessary, in this size furnace. Taking larger figure the cost of energy per ton is $2.06.

Royalty. In the United States, on the basis of a plant of 50 tons daily the royalty would be about 50 cents per ton.

SUMMARY OF COST

Interest charges	$0.74
Labor	2.62
Lining	1.50
Keeping furnace warm and cooling	0.11
Royalty (approx.)	0.50
Energy for melting and refining	2.06
Total	$7.53

The figure $7.53 is the working cost which must be added to the cost of the materials in order to find the cost of crucible quality steel from scrap. The above figure would be more reasonable with larger furnaces.

Cost of Production. (2) *For a two-ton, 300 kw., three phase tilting furnace.—Molten converter steel to quality steel for castings.*

Cost with all accessories about $12,500. With 10 per cent for interest charges gives $1250 per annum. Allowing 250 working days in the year and 16 tons per day gives 4,000 tons per annum or $0.31 per ton of steel.

Interest charges per ton of steel	$0.31
Power for heating up, per ton of steel	0.02
Power for refining, allowing upper figure of 300 kw-hr. at $20 per kw-yr.	0.68
Air cooling of furnace core	0.01
Cost of lining every ten days. (German figure.)	0.35
Wages allowing $16 per day	1.00
Royalty on basis of 50 tons daily	0.50
Total cost per ton of steel	$2.87

This figure would give a good idea of the cost of converting molten pig iron into steel, exclusive of the ferro alloys.

Cost of Production. (3) *For a five ton, 550 kw., three phase tilting furnace.—Molten converter steel to crucible quality steel.*

Cost with all accessories about $22,000. With 10 per cent for interest charges gives $2,200 per annum. Reckoning 250 working days in the year, each one with eight heats of five tons, the yearly production would be 10,000 tons, or $0.22 per ton for interest charges.

Interest charges	$0.22
Power including heating up. For a monthly average of 230 to 280 kw-hr. per ton and taking the higher figure	0.64
Cost of lining. (German figure.)	0.30
Wages allowing $20 per day	0.50
Air cooling of core	0.01
Royalty (Approx.) Basis of 50 tons daily	0.50
Total	$2.17

Cost of Production. (4) *For a seven ton, 750 kw., three-phase, 25-cycle, 0.6-power factor tilting type furnace.—Converting molten converter steel into high grade rails. For analysis see page 626.*

Cost with all accessories $27,000. Interest charges at 10 per cent gives $2700 per annum. Allowing 100 tons daily (the makers claim a production of 140 tons) and 250 working days in the year gives a yearly production of 25,000 tons of rail steel and interest charges per ton of steel = $0.11.

Interest charges	$0.11
Power for heating up	0.01
Power for refining. Makers claim 100 kw-hr. per ton. Allowing 150 kw-hr. per ton	0.34
Power for cooling	0.01
Cost of lining. Pneumatically tamped. Two foremen and six laborers or $21.00 daily. Per ton	0.02
Cost of lining material. (German figure)	0.06
Wages. Two head melters at $3.00 and 10 helpers at $2.50 $31.00 per ton	0.31
Royalty on rail steel, one furnace in U. S	0.35
Total	$1.21

This is the conversion cost which added to the value of the pig and ferro alloys, etc., gives the cost of steel for rails. The Prussian Railways paid $10 extra per ton for rails made in this furnace and were well pleased with the product.

Cost of Production. (5) *For a seven-ton, 750-kw., three-phase, 25-cycle, 0.6-power factor, tilting type furnace.—Molten converter steel to highest quality steel. For analysis see page 626.*

This furnace will produce about half the steel of this quality as when working on rail steel or 50 tons daily.

The cost per ton under these conditions is about $2.00 per ton including royalty.

SUMMARY OF COSTS OF PRODUCTION EXCLUSIVE OF MATERIALS

1.5-ton furnace melting scrap and refining to pour high grade steel for castings. Per ton	$7.53
2-ton furnace refining molten converter steel to high grade steel. Per ton	2.87
5-ton furnace refining molten converter steel to high grade steel. Per ton	2.17
7-ton furnace refining molten converter steel to high grade steel. Per ton	2.00
7-ton furnace refining molten converter steel to high grade rails. Per ton	1·21

DISCUSSION ON "THE REFINING OF IRON AND STEEL BY INDUCTION TYPE FURNACES," LOS ANGELES, CAL., APRIL 25, 1911.

R. J. C. Wood: I notice here it says one-third of the energy is used in radiation losses. If the radiation loss amounts to one-third of the working amount, I don't see how they could get 97 per cent efficiency.

R. W. Van Norden: I cannot answer the question exactly but I imagine that what Mr. Elwell means is the furnace or transformer efficiency. Taking into consideration the heating of the hearth, it would not have that efficiency. There are no published figures on the furnaces on the Pitt; there are no induction furnaces there and I don't believe they intend to install any as they are very well satisfied with the electrode type. They are not the Heroult furnace, but a modification of an earlier type which the operators have worked out themselves. I can not give any figures on operation and costs. I understand that refined pig-iron can be laid down in San Francisco at $18 a ton, or less.

Earl W. Paul: I am slightly familiar with the process of reducing iron ores and the making of steel by the Bessemer and open hearth processes, and know how important it is that the product of the furnaces should show a uniform chemical analysis.

From the data given in the paper it appears that the product of the electric furnace runs remarkably uniform, and further that at small cost the iron or steel can be kept in a molten condition and treated until the desired chemical analysis is obtained.

Another very important feature, is that, the chilling of the furnace is not a serious matter. Should the furnace chill, the current can be turned on the solid mass and in a few hours is remelted. The chilling of the present type of furnace, usually means quite a serious loss.

J. J. Frank: I had occasion during the last week to visit one of the large steel manufacturing companies, and I saw an arc furnace and discussed it with one of the attendants, and he remarked that the handling of the electrode is one of the most difficult things. It was a Heroult furnace. When the carbon drops off into the bath, it of course affects the chemical analysis. The attendant also told me that while the steel produced met the chemical analysis, it did not always live up to the same physical requirements; that is, the results vary.

I am a little familiar with the induction type furnace, and I would like to add to the remarks of the author by saying that there is a type of induction furnace in which the primary winding is a hollow tube. This primary is supplied with current from a transformer stepping it down from 10,000 volts or any other voltage which may be available. Water flowing in this copper tube keeps it cool, so a very high current density is possible, and it will influence the operation of the transformer because of its increased weight. One of the objections to the arc furnace, whether it is the Heroult or any other furnace, is the heat from the furnace affects the reliability of the induction motor operating the electrodes. At first glance, that is not very important, but when you consider that any fumes which pass off naturally ascend and if the induction motors are directly over the furnace the fumes will influence the insulation and the action of the induction motors, it is more important; and that, I believe, is one of the serious problems in the construction of these arc furnaces; namely, to take care of and protect the induction motors from these fumes.

Another problem is the installation of the induction motors and the gearing that is necessary. The induction motor must be clamped directly to the electrodes, and that must be the potential of the furnace. Another objection is, in an arc furnace, the arc may create high frequencies, which being transformed to the high potential side of the transformer, affect the operation and may disturb the whole system so that it may induce stresses in the transformer which cannot be foreseen until the operation is begun.

H. H. Sinclair: Are the furnaces mentioned treating pig iron into steel? I had the impression, and I would like to ask Mr. Van Norden if it is not true that in the works of the Noble Steel Company, they were treating iron ore and converting it into pig iron.

R. W. Van Norden: There is no attempt to refine the iron. Pig iron only is made from iron ore.

H. H. Sinclair: What type of iron ores do they get, magnetic ore or one of the others?

R. W. Van Norden: It has a high percentage of iron, about seventy per cent.

H. H. Sinclair: I think that they treat a magnetite ore in Shasta County.

J. J. Frank: With the induction type of furnace it is possible, as I stated, to use a transformer scaling down from any high voltage to the primary of the furnace and that primary charge might be a very minor one and is copper through which water circulates and the insulation is just rubber hose. The problem there is a very simple one.

Another point raised here is the variation of the voltage. That may be very readily done in the induction type by an ordinary regulator. It would make it very easy to regulate and momentarily give 200 per cent overload current if it was desired to very rapidly heat the charge.

R. W. Sorensen: In connection with this kind of work I believe there is one feature the effect of such a load upon the supply source which must be carefully considered. The author states that a better load is put upon the line when the induction furnace rather than a furnace of the electrode type is used, but has not called attention to the fact that with the use of the electrode type of furnace it is impossible to balance the polyphase power line except by means of a motor-generator set which changes the polyphase current to either single phase alternating, or direct current; because of that old rule " a single phase current pulsating power cannot be turned into an equivalent polyphase current, or *vice versa*, without some rotating devise which will balance the transfer of energy."

Another point in favor of the induction type of furnace is that there is less liable to be such rapid fluctuation of current as will probably occur with the electrode type when there is any change in position of electrodes or in the conducting property of the charge. Suppose your electrode moves slightly. If you have, as the author states, 6200 amperes, for instance, and the voltage produced by the varying of that current is anything like what we have with transmission lines or was mentioned a few moments ago, *viz.*, 200 times the current interrupted, you would have a tremendous amount of power that would have to be taken care of somewhere. Now suppose your current varies but ten per cent, that would still leave you something over a hundred thousand volts to be taken care of in what is probably a low voltage system. Of course, it is very probable that the voltage variation in the supply transformer will not be anything like the voltage thus induced on a line but on the other hand it may be more. Just what law this would follow I don't know, but I am quite sure that a transformer for this kind of service should be made especially for this service because if these larger variations take effect on transmission lines, a certain percentage of that voltage variation must take place where you have magnetic circuit in the transformer, so if you are going to use transformers, for such service, special care should be exercised or you will have trouble with your transformers supplying to electrodes such large current as 6200 amperes.

C. W. Koiner: In addition to what Professor Sorensen has just stated, I would add that these furnaces operate to give the companies additional field in which to sell current. In 1904, we are told there were only four electric furnaces in existence, and they were in Europe. Today we have over one hundred, ranging in size from 100 lb. to 15 tons. These are used in this country and in Europe. There has been a furnace in operation in South Chicago for the past year or so and I understand it gives very good results. We are also told that current is now being sold at off-take periods for the refining of steel at a cost of about one cent per kw-hr. This has been going on for about a year. The cost is very reasonable when you consider it in comparison with the cost in refining operations.

Budd Frankenfield: It seems to me we along the Coast here should be especially interested in electric furnaces, not for the smelting of steel particularly, but electric furnaces in general. I would not regard it as an off-take proposition, because in furnace industries such as we have at Niagara, they operate twenty-four hours in the day. They have a large enough load factor to keep up a continuous demand for current.

Another thing is the large amount of power that can be used by these furnaces. For instance, it would not take a very large plant in some electrochemical or electric furnace industry to use the entire Owens River power which we expect here, to found an industry and employ men, instead of spending a great deal of money for a general distribution system. I have no doubt there are plenty of raw materials on the Pacific Coast to be utilized in making furnace industries, such as are in existence in Europe, a good proposition and a success.

C. H. Vom Baur: The Kjellin induction furnaces being put out today are chiefly of the small, laboratory sizes, as the Rochling-Rodenhauser electric induction furnaces have three distinct advantages over the Kjellin, which give it undoubted preference as follows:

1. It operates on polyphase current and in the one and two-ton sizes at 50 or 60 cycles with a power factor of 0.7 to 0.8.

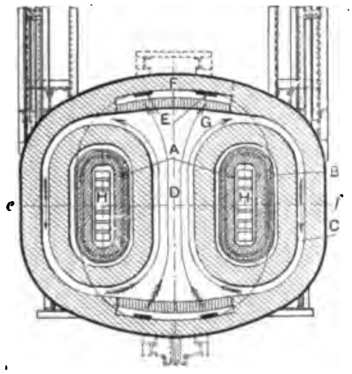

FIG. 1

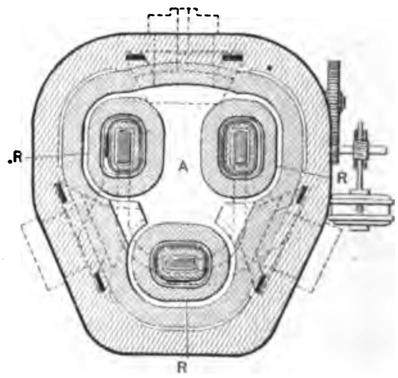

FIG. 2

2. Owing to the different shaped hearth, that is, having two or three intersecting circuits making a large hearth in the center, as shown in Figs. 1 and 2 herewith, and on account of the auxiliary, secondary current which is usually 30 per cent of the whole, which also goes through the bath, the so-called " pinch effect " or interruption of the circuit is absolutely precluded. This was one of the greatest disadvantages of the Kjellin furnace.

3. The larger hearth thus made allows a *rapid* refining of steel.

One of the greatest advantages of the induction furnace not mentioned by Mr. Elwell is its aptitude for thorough deoxidation of the metal and absence of segregation.

Relative to the magnesite lining, improvements have lately been made so that this now lasts three weeks instead of two weeks as formerly.

One of the metallurgical features, not mentioned, which is of some moment as it saves time, is that the power and thence the maximum heat remains on the furnace when rabbling off the slag. In an arc furnace the carbons have to be withdrawn for this operation.

As Mr. Elwell assumes that current is made for $20 a kw-yr., it is hardly possible that current would be used all the time and the practical probability is that the current would be in use not over ⅔ or ¾ of the time, costing therefore 33 or 50 per cent more per kw-hr. It would perhaps have been better if Mr. Elwell had also added the cost of the usual ferro alloys and fluxes, such as lime, roll-scale, etc., to the conversion cost for the sake of completeness. These fluxes and additions usually cost from 60 cents to $1 per ton.

The summary of costs of production inclusive of fluxes, taken at $1, and allowing for actual cost of electricity, at 50 per cent increase, would more nearly be as follows:

1.5-ton furnace melting scrap and refining to pour high grade steel for castings. Per ton	$9.61
2-ton furnace refining molten converter steel to high grade steel. Per ton	4.22
5-ton furnace refining molten converter steel to high grade steel. Per ton	3.49
7-ton furnace refining molten converter steel to high grade steel. Per ton	3.18
7-ton furnace refining molten converter steel to high grade rails. Per ton	2.39

C. F. Elwell: The efficiency of 97 per cent refers to the electrical efficiency of the transformer. The core is built up of slightly heavier iron than usual and these laminations are separated by sheets of India paper. The core and copper loss in the primary is under these circumstances about 3 per cent. Similar electrical losses, not radiation losses, in the arc furnace are very much greater. The high resistance carbon electrodes dissipate a large amount of energy. It is true that the radiation loss is high as evidenced by the amount of power necessary to keep the furnace from freezing over a period of rest. The arc furnace is notorious for its radiation for in my experience it was very difficult to keep a top on one, and without a top the heat in the furnace room was unbearable. One point in favor of the Rochling Rodenhauser furnace is that most of the bath can be well covered to prevent radiation as it is unnecessary to remove the covers except for relining.

In reply to Mr. Sinclair, the iron ore in Shasta county has an analysis as follows: Fe 69.9 per cent; Fe_3O_4 89.4 per cent; Fe_2O_3 0.3 per cent; Mn O 0.18 per cent; Mg O 0.3 per cent; SiO_2 2.4 per cent; P 0.011 per cent; S 0.009 per cent.

Considerable pig iron has been made but as yet the furnace does not last long enough to bring the cost per ton for furnace relining to a reasonable figure.

Professor Sorensen sounds a note of warning which it might be well to heed even if some of us have had no trouble from this source. I have had experience with 22,000 amperes and the whole load has been dropped suddenly many times but no ill effects have been noticed in the transformers.

A paper presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25, 1911.

CISOIDAL OSCILLATIONS

BY GEORGE A. CAMPBELL

The oscillations here defined as " cisoidal oscillations " are those of the form

$$C \operatorname{cis} pt = C(\cos pt + i \sin pt) = Ce^{ipt} \tag{1}$$

where t is the time, e the Napierian base, $i = \sqrt{-1}$ the imaginary symbol,[1] and cis an abbreviation for the complete trigonometric expression. The constants C and p may be any scalar quantities, either real or complex. The oscillations are sustained, logarithmically damped or aperiodic, according as the time coefficient p is real, complex, or pure imaginary. The following discussion will, in general, apply indifferently to all three cases.

The use of the term " cisoidal oscillations " emphasizes the distinctive character of the subject, while tending to keep in mind the close connection between these oscillations and sinusoidal oscillations. The fact that one of the algebraic curves is called a " cissoid " can hardly lead to confusion.

The practical importance of cisoidal oscillations rests upon the following properties:

1. In all cases where the principle of superposition holds, any

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[1] The use of i (or Greek ι) for the imaginary symbol is nearly universal in mathematical work, which is a very strong reason for retaining it in the applications of mathematics in electrical engineering. Aside, however, from the matter of established conventions and facility of reference to mathematical literature, the substitution of the symbol j is objectionable because of the vector terminology with which it has become associated in engineering literature, and also because of the confusion resulting from the divided practice of engineering writers, some using j for $+i$ and others using j for $-i$.

oscillation may be regarded as a compound cisoidal oscillation, *i.e.*, the algebraic summation of simple cisoidal oscillations.

2. Cisoidal oscillations are uniquely simple because the ratio of the instantaneous electromotive force to the instantaneous current is not a function of the time.
3. Cisoidal oscillations involve scalar magnitudes only so that all algebraical relations and operations applying to the real physical phenomena may be extended to them.
4. The solution for cisoidal oscillations in any finite network may be written down directly, without solving differential equations or the use of integration or differentiation.

SCALAR CHARACTER OF CISOIDAL OSCILLATIONS

As complex quantities and exponential functions of complex quantities follow the laws of ordinary algebra, they introduce scalar quantities and not vector quantities. This is a matter of great importance, since ordinary algebra is simpler than vector algebra. The wide-spread use of the term "vector" in connection with complex quantities in alternating current theory is unfortunate for it is logically incorrect, and so has led to confusion, and it also tends to divert attention from the algebraical theory of complex quantities, which is of great practical assistance in the treatment of cisoidal oscillations.

When the direction of a current is confined to one or the other of two opposite directions by the use of a linear conductor, we can vary its scalar magnitude only; it is no more correct to speak of representing this scalar quantity by a vector when it is complex than when it is real. It is only when the electrical phenomena takes place in two or three dimensions in space that vector variables are involved in the mathematical treatment.

With complex quantities the power continues to be the product of electromotive force and current. A steady imaginary current flowing through a resistance, therefore, dissipates negative real power, that is, energy is absorbed by the electrical phenomena taking place, which tends to cool the conductor. Similarly the magnitudes of the kinetic energy of an inductance and the potential energy of a condenser are real negative quantities in case the instantaneous current and potential are pure imaginary. As the power with complex quantities may be either positive or negative, or in general have any argument, the total power in a portion of a network, such as two or more resistances, may vanish because the several powers in the individual elements mutually cancel when added together.

If the current and electromotive force are each cisoidal the associated power is also cisoidal with a time coefficient equal to the algebraical sum of the time coefficients of the electromotive force and current; when these two coefficients are equal and opposite in sign the power is constant with respect to the time.

We might have defined the cisoidal oscillation using throughout $-i$ in place of i, which would change all quantities, including the impedances, to their conjugates. But we follow, of course, the general practice of taking positive quantities as the norm, in consequence of which the sign for inductive reactances is positive, and the sign for capacity reactances is negative.

CORRELATED OSCILLATIONS

The complete formal solution of a sinusoidal alternating current problem by the aid of complex quantities involves the following steps:

1. Resolution of the periodic data into the sum of cisoidal oscillations having the time factors cis $(+pt)$ and cis $(-pt)$.
2. Solution of the problem for the cis $(+pt)$ component taken alone; the solution for the cis $(-pt)$ component is then obtained directly from this by changing all complex quantities to their conjugates.
3. Superposition of these two cisoidal solutions to obtain the real physical oscillation.

It is however not necessary to carry through the formal proof in individual cases, this being replaced by the following correlation between the real and the complex oscillations.

If throughout any invariable network a cisoidal oscillation and a cosinusoidal oscillation (all of one time coefficient p) have electromotive forces and currents of the same effective values (moduli) and angles (arguments), they will be called correlated oscillations.

The alternating powers involved throughout correlated oscillations are equal to each other as regards amplitudes (moduli) and angles (arguments); the cosinusoidal oscillation having also non-alternating power components which are equal, as regards amplitudes (moduli) and phase angles (arguments), to the powers which would be associated with the correlated cisoidal electromotive forces taken with the conjugates of the correlated cisoidal currents.

Or in other words:

The instantaneous cosinusoidal electromotive forces and currents are the real components of the correlated cisoidal electromotive forces and currents multiplied by the factor $\sqrt{2}$.

The instantaneous powers involved in a cosinusoidal oscillation are equal to the real components of the cisoidal powers in the correlated cisoidal oscillation, augmented by the real components of the powers involved in the correlated cisoidal oscillation after changing the currents (or electromotive forces) to their conjugates.

In the typical notation the correlated oscillations thus defined have, if $p=p_1+p_2 i$

Instantaneous	Cisoidal	Cosinusoidal	
e.m.f.	$E e^{ipt}$	$\sqrt{2}\lvert E\rvert e^{-p_2 t}\cos(p_1 t+arg E)$	
current	$I e^{ipt}$	$\sqrt{2}\lvert I\rvert e^{-p_2 t}\cos(p_1 t+arg\ I)$	(2)
power	$E I e^{2ipt}$	$\lvert E I\rvert e^{-2p_2 t}\left[\cos(2p_1 t+arg(E I))+\cos arg\frac{E}{I}\right]$	
impedance	$\frac{E}{I}$	$\frac{E}{I}\frac{\cos(p_1 t+arg E)}{\cos(p_1 t+arg\ I)}$	

In much of the actual algebraical work connected with cisoidal oscillations, we may drop the time factors e^{ipt} and e^{2ipt} and write only E, I and $E\,I$ (or $P=E\,I$) with considerable resulting simplification and no liability of introducing confusion.

It is to be particularly noted that the magnitudes which are equal to the corresponding cisoidal moduli are the *effective* values of the cosinusoidal electromotive forces or currents and the *amplitudes* of the cosinusoidal power components. On the other hand, the cisoidal arguments are uniformly equal to the corresponding real angles, this angle reducing for the non-oscillatory cosinusoidal power component to the constant angle of lag or lead.

The preceding statements supply the working rules for making the change from the real physical cosinusoidal oscillation to the ideal cisoidal oscillation and vice versa. This connection is, as regards electromotive force and current, one of mutual resolvability as is expressed by the following formulæ:

$$\sqrt{2}|C|e^{-p_2 t}\cos(p_1 t+arg\ C)=\frac{1}{\sqrt{2}}Ce^{ipt}+\frac{1}{\sqrt{2}}C'e^{-ip't}$$

$$\begin{aligned} C e^{ipt}=&\frac{1}{\sqrt{2}}\left[\sqrt{2}|C|e^{-p_2 t}\cos(p_1 t+arg\ C)\right]\\ &+\frac{i}{\sqrt{2}}\left[\sqrt{2}|C|e^{-p_2 t}\cos\left(p_1 t+arg\ C-\frac{\pi}{2}\right)\right]\end{aligned} \tag{3}$$

the first giving the cosinusoid in terms of the correlated cisoid and its conjugate cisoid, the second giving the cisoid in terms of the correlated cosinusoid and the consinusoid with its phase retarded 90 degrees. On account of this mutual resolvability either the cisoidal oscillation or the cosinusoidal oscillation may be regarded as being obtained by summation from the other.

If any particular cisoidal or cosinusoidal oscillation is possible the correlated oscillation is also possible.

It is somewhat arbitrary as to the exact functions which we define as correlated oscillations. The sine might have been taken in place of the cosine and the amplitudes in place of the effective values, but on the whole these alternatives do not seem to afford quite the same convenience, but only because the statements become slightly more involved. We shall however continue to use the term " sinusoid " as the general designation for the sine function having any arbitrary phase angle including thereby the cosine function.

The correlation between the sinusoidal oscillations and cisoidal oscillations is so simple that it is not ordinarily necessary to indicate the step from one to the other in special applications of the method. But this omission has led to the cisoidal solution being in some way regarded as representing the actual sinusoidal oscillation, which is not the case as is very clearly shown by the power relations. It is therefore necessary to lay emphasis upon the fact that the use of complex quantities affords an indirect method, and not a symbolic method of solving real cases of oscillations and that the complete application of the method involves an initial algebraical resolution of the real data and a final algebraical summation of the complex results as an essential and integral part of the method.

GENERAL EQUATIONS FOR ANY NETWORK

In any invariable network the actual distribution of current due to any impressed electromotive forces is such as to make the power dissipated assume the stationary value[2] *which is consistent with the conditions imposed by current continuity and the conservation of*

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[2] A function assumes a stationary value when it is not altered by any possible infinitesimal change in the system of variables upon which it depends; the first derivatives of the function, with respect to each of a set of independent variables is zero at a stationary value. Stationary is thus a generalization of maximum, minimum and point of inflection, but without any implication beyond the vanishing gradient.

energy. The theorem assumes that each branch or circuit contains resistance, a condition which corresponds to the physical fact and involves no theoretical limitation as the resistances may be as small as desired, or any number of the resistances may be allowed to vanish completely after playing their part in the formation of the general solution.

This theorem may be established directly from the principles of dynamics, but we will here show that it is the equivalent of the generalized Kirchhoff equations.

The condition imposed by the conservation of energy may be expressed in the form of the equation of activity by equating the total power supplied by the impressed forces to the sum of the powers taken separately by the resistances (including conductances), self-inductances, mutual inductances and capacities. That is

$$\sum e_q i_q = \sum R_q i_q^2 + \frac{d}{dt}\left(\sum \frac{1}{2} L_q i_q^2 + \sum M_{qr} i_q i_r\right)$$

$$+\frac{d}{dt}\sum \frac{(\int i_q\, dt)^2}{2\, C_q} = \sum R_q i_q^2 + \sum L_q i_q \frac{d\, i_q}{d\, t}$$

$$+\sum M_{qr}\left(i_q \frac{di_r}{dt} + i_r \frac{di_q}{dt}\right) + \sum \frac{i_q \int i_q\, dt}{C_q} \qquad (4)$$

The condition of continuity may be introduced by expressing the currents in terms of any set of independent, circuital currents $c_1, c_2, \dots c_n$, where n is the number of degrees of freedom of the network. This gives one equation for each of the l branches

$$i_q = a_{q1} c_1 + a_{q2} c_2 + \dots a_{qn} c_n \qquad (q = 1, 2 \dots l) \qquad (5)$$

where the coefficient $a_{qs} = \pm 1$ or 0, according as branch q is or is not a part of circuit s, the sign in the first case being positive, or negative, according as the positive direction for the branch and for the circuit are or are not concurrent.

The power dissipated $\Sigma R_q i_q^2$ is a homogeneous expression of the second order in terms of the n independent circuital currents, while the remainder of equation (4) is of the first degree in these currents. The stationary value for the power dissipated under the assumed conditions will therefore be found by first introducing the multiplier $\frac{1}{2}$ as a coefficient for $\Sigma R_q i_q^2$ and then differentiating (4) with respect to c_s* which gives the following set of n equations:

$$\sum a_{qs}\, e_q = \sum a_{qs}\, R_q\, i_q + \sum a_{qs}\, L_q \frac{di_q}{dt} + \sum M_{qr}\left(a_{qs} \frac{di_r}{dt} \right.$$

$$\left. + a_{rs} \frac{di_q}{dt} \right) + \sum a_{qs} \frac{\int i_q\, dt}{C_q}, \quad (s = 1, 2, \ldots n) \qquad (6)$$

The set of equations (6) is identical with the generalized Kirchhoff equations of electromotive force for the n circuits taken in the positive direction for the currents c_s, since the coefficients a_{qs} and a_{rs} provide the proper sign for each effective electromotive force occurring in these circuits and exclude all electromotive forces not occurring in the several circuits. The Kirchhoff laws and the above condition of stationary dissipation are therefore mutually equivalent.

In subsequent work it will be more convenient to merge the conditions of continuity in the equation of activity (4) than to use separate equations such as (5) to cover these conditions. This may be accomplished either by reducing the currents appearing in the equation of activity to a number equal to and so chosen as to correspond with the degrees of freedom of the network, or by adding fictitious currents which correspond to the significant branch points; *i.e.*, points, in excess of one in each connected part of the system, at which three or more branches meet. Their number being m, the number of branches (including each isolated closed circuit as a branch) being l, and the degrees of freedom being n, the relation holds, $n = l - m$.

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*To prove this rule let $f = m^{-1} F_m + n^{-1} F_n$, (where F_m and F_n are homogeneous functions of $x, y, z, \ldots$ of order m and n) be given its stationary value, which requires $D_x f = D_y f = D_z f = \ldots = 0$. The sum of the differential coefficients multiplied in order by $x, y, z, \ldots$ consequently vanishes, that is,

$$x\, D_x f + y\, D_y f + z\, D_z f + \ldots = 0, \text{ or}$$

$$m^{-1} [x\, D_x\, F_m + y\, D_y\, F_m + \ldots] + n^{-1} [x\, D_x\, F_n + y\, D_y\, F_n + \ldots] = 0.$$

By the elementary property of homogeneous functions the bracketed expressions are equal to $m\, F_m$ and $n\, F_n$ so that the relation $F_m + F_n = 0$ is satisfied at the stationary value of f. This relation may be considered as a prescribed condition without having any effect on the final stationary result, but we could then eliminate F_m from the original expression for f and write $f = (n^{-1} - m^{-1})\, F_n$, whence the stationary value of F_n, with the condition $F_m + F_n = 0$, corresponds to the unconditioned stationary value of f. The application in the paper is for $m = 1$, $n = 2$ and $f = F_1 + \frac{1}{2} F_2$.

The first transformation is accomplished by replacing the branch currents i_q in (4) by circuital currents such as c_s by the aid of such equations as (5). Rearranging the terms the form of the equation of activity may still be kept the same as in (4), but all quantities, e, i, R, L, M, C now refer to complete circuits and not to individual branches.

The second transformation follows from the identity of the condition of continuity for currents converging on branch point f,

$$\varphi_f = M_{f1} i_1 + M_{f2} i_2 + \;.\;.\;.\; M_{fr} i_r \;.\;.\;.\; + M_{fl} i_l = 0, \qquad (7)$$

$$M_{fr} = \pm 1 \text{ or } 0, \quad f = (l+1, \;.\;.\;.\; l+m),^*$$

with the condition that a fictitious circuit devoid of resistance, inductance, and capacity can experience no resultant electromotive force whatever be the currents flowing in the branches 1, 2, . . . r . . . l with which it has mutual inductances M_{f1}, M_{f2}, . . . M_{fr} . . . M_{fl}. This physical consideration shows that the conditions of continuity will be included in (4) by extending the summation to cover fictitious circuits devoid of resistance, etc., and with zero mutual inductances between each other and all real branches excepting only $M_{fr} = \pm 1$ when the real branch r terminates in the branch point f, the sign being positive or negative at the positive or negative end of the branch respectively.

To prove the same analytically we multiply each equation of (7) by i_f, take their sum, differentiate with respect to t and add this expression, which we may denote by

$$B = -\frac{d}{dt} \sum i_f \varphi_f = -\frac{d}{dt} \sum\sum M_{fr} i_f i_r$$

to (4), which is permissible since B must be equal to zero. On differentiating (4) (with multiplier $\frac{1}{2}$ added to $\Sigma R_q i_q^2$) with respect to the real current i_q, B introduces the new terms $\sum \frac{di_f}{dt} \frac{d\varphi_f}{di_q}$ to (6), and these are precisely the additional terms required by the conditions of continuity, since $\frac{di_f}{dt}$ plays the part of an undetermined multiplier. Again differentiation

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*These m fictitious circuits are numbered in sequence with the l real branches so as to make it possible to employ throughout the same notation for circuit constants and currents, *viz.*, R_f, i_f, etc.

with respect to the fictitious current i_f gives $\frac{d}{dt}\varphi_f=0$ or $\varphi_f=0$, the constant of integration being zero, as infinite energy in the fictitious circuits is to be excluded, and these are the equations of continuity (7). Thus after the addition of B, equation (4) includes all of the conditions of continuity.

It will be assumed in the subsequent work that the network under discussion has been transformed into a set of simple circuits, thus reducing the conditional equations to the equation of activity. The coefficients occurring in this equation and the number of currents entering it will depend upon the particular choice of simple circuits, but the general discussion of the network will be, to a considerable extent, independent of the choice of the simple circuit system. In concrete applications it will be advantageous, in order to have as few variables as possible, to use the first of the above transformations. In general work, however, the second transformation presents the distinct advantage of including all branches symmetrically.

GENERAL EQUATIONS FOR CISOIDAL OSCILLATIONS

For cisoidal oscillations the preceding theorem may be given the following still simpler form:

The activity of the external sources of power which produce a steady cisoidal oscillation in any invariable network assumes the stationary value which is consistent with the conditions imposed by current continuity and the conservation of energy.

With cisoidal oscillations the differentiations and integrations indicated in the equation of activity (4) may be carried out and after dividing by the common factor e^{2ipt} and introducing the self and mutual impedances $Z_{qq}\,(=Z_q)$, $Z_{qr}\,(Z_{rq}=Z_{qr})$, the equation becomes

$$\sum_{q=1}^{q=n} E_q I_q=\sum_{q=1}^{q=n} Z_q I_q^2+2\sum_{r>q=1}^{q<r=n} Z_{qr} I_q I_r=\sum_{q=1}^{q=n}\sum_{r=1}^{r=n} Z_{qr} I_q I_r \qquad (8)$$

The left-hand and the right-hand sides of this equation are homogeneous functions of the first and second orders in terms of the currents. Comparison with the first and second order terms in (4) shows that the right-hand side of equation (8), which is the total power taken by the network, may be substituted in the general theorem for the power dissipated. Or, since the two sides of equation (8) are always equal, the left-hand side, which is the power supplied by the sources, may equally well be taken; whence the above theorem follows.

Stationary activity involves stationary driving point impedance and the theorem might be restated in terms of the impedances.

Differentiating equation (8) with respect to each of the n currents (after introducing the multiplier $\frac{1}{2}$ for the right-hand side) we have for the general equations determining the distribution of current:

$$\begin{array}{l} Z_{11} I_1 + Z_{12} I_2 \ldots\ldots\ldots\ldots\ldots\ldots + Z_{1n} I_n = E_1 \\ Z_{21} I_1 + Z_{22} I_2 \ldots\ldots\ldots\ldots\ldots\ldots + Z_{2n} I_n = E_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ Z_{n1} I_1 + Z_{n2} I_2 \ldots\ldots\ldots\ldots\ldots\ldots + Z_{nn} I_n = E_n \end{array} \qquad (9)$$

The currents are therefore

$$I_q = \sum_{r=1}^{r=n} \frac{A_{qr}}{A} E_r$$

where A is the determinant of the impedances occurring as coefficients of the currents in (9) and A_{qr} ($= A_{rq}$) is the co-factor of Z_{qr} in this determinant. Substituting in equation (8), we find that the stationary power, that is the power which is actually expended on the network, is

$$P = \sum_{q=1}^{q=n} \sum_{r=1}^{r=n} \frac{A_{qr}}{A} E_q E_r = \frac{A_e - A}{A} \qquad (10)$$

where A_e differs from the determinant A only in having each element Z_{qr} augmented by $E_q E_r$.

Self- and mutual-admittances may be substituted for the self- and mutual impedances in the right-hand side of equation (8), the form of the expression being kept unchanged by simultaneously substituting potential differences for currents. The solution in terms of the admittances will then be obtained from a determinant in which the admittances enter precisely as do the impedances in "A". For certain problems, as will be readily seen, the admittance determinant is much more convenient than the impedance determinant. While the impedance determinant is made the special object of discussion in the remainder of this paper, it is to be understood that corresponding applications may be made of the admittance determinant.

THE DISCRIMINANT OF A NETWORK

The discriminant A of a network is defined as the determinant having the element Z_{qr} in the qth row and rth column; Z_{qr} being the mutual impedance between circuits q and r or the self-impedance of circuit q when $q=r$; the determinant to include the self- and mutual impedances of the system of simple circuits obtained by eliminating the branch points by closing each branch on itself and replacing each branch point, in excess of one in each connected part of the system, by a fictitious circuit of zero self-impedance connected by mutual impedances $+i$ and $-i$ to the several branches which have their positive or negative ends respectively at this branch point.

This will be taken as the normal form of the discriminant, since it is symmetrical in terms of all of the real branches and real closed circuits of the network. That it is also essentially symmetrical in all of the branch points follows from the fact that the value of the determinant is independent of the choice of the particular branch points to be excluded. The discriminant A is of fundamental importance in the discussion of the network because all effective impedances of the network may be determined directly from its array.

The degree of A in terms of the actual impedances of the network is equal to the number of degrees of freedom of the network, which is the same as the number of branches, reduced by the number of branch points, omitting one in each connected part of the system. The determinant A is of the first degree in each self-impedance, and of the second degree in each mutual impedance when physically considered, that is when the order of the subscripts is ignored $(Z_{rq} \equiv Z_{qr})$.

The co-factor of the product of the elements located at the intersection of rows j, q, s, . . . with columns k, r, t . . . respectively of determinant A will be denoted by $A_{jk.qr.st}$ . . . $=A_\alpha$, where α stands for the paired list $j\,k\,.\,q\,r\,.\,s\,t$ . . . Thus A has the value $A_\alpha Z_{jk} Z_{qr} Z_{st}$ . . . in case all other elements in rows j, q, s, . . . and columns k, r, t, . . . are replaced by zero; the arithmetical value of the co-factor depends only on the choice of rows j, q, s, . . . and columns k, r, t . . . which occur in the subscript; its algebraical sign depends upon the sequence of the rows and columns and is changed by each inversion of rows or columns. It follows that if the same row or column occurs twice in the subscript the value of the co-factor is zero. Where we have occasion to restore one or more rows and an equal number of columns of A to A_α, the elements to be removed from α will be indicated as a divisor of the subscript α. The algebraical value of the expression $A_{\frac{\alpha}{\beta}}$ is uniquely and completely determined by canceling the denominator against a part or the whole of the numerator, making inversions, if necessary, in the numerator or denominator; in case the denominator cannot be entirely eliminated by this process the symbol indicates a determinant with identical rows or columns, and it is therefore equal to zero. For example:

$$A_{\frac{11\cdot22}{12}} = -A_{\frac{12\cdot21}{12}} = -A_{21}, \quad A_{12\cdot13}=0, \quad A_{\frac{12\cdot23}{34}} = 0, \quad A_{\frac{11\cdot22}{12\cdot21}} = -A$$

$$\text{and } A_{jk.qr.st\dots} = -\frac{D_{z_{jk}}\,D_{z_{qr}}\,D_{z_{st}}\cdots A}{2^{(\delta_{jk}+\delta_{qr}+\delta_{st}\,\dots)}}, \tag{11}$$

$$Z_{rq} \equiv Z_{qr} \not\equiv 0, \qquad \delta_{qr} = \begin{cases} 0 \text{ if } q=r \\ 1 \text{ if } q \neq r \end{cases}$$

where the differentiations correspond to actual physical variations in the impedances and therefore treat mutual impedances with interchanged subscripts as identical.

By applying the following rules the expanded expressions for A and its co-factors may be written down directly from the simple circuit system replacing the network, without reference to the determinant. This method of expansion is often more convenient than the use of the ordinary rules for expanding the determinant.

A is the sum of all possible products in which each circuit is represented either by its self-impedance or by its mutual impedance to another circuit, the mutual impedances occurring, however, in closed cycles of two or more constituents only, so that the subscripts may be written $k\,m$, $m\,q$, $q\,u$, . . . $w\,k$, each cycle introducing the sign-factor + or − according as the cycle contains an odd or an even number of terms; each cycle of three or more circuits also introducing the factor 2 to care for the alternative way of associating the mutual impedances and the circuits of the cycle.

A_{qq} is the coefficient of Z_{qq} in A, *i.e.*, A_{qq} is the value taken by A when circuit q is removed from the network.

A_{qr} is the coefficient of Z_{qr} *after* writing A in symmetrical form with respect to Z_{qr} and Z_{rq}, *i.e.*, A_{qr} is the value taken by $A \div Z_{qr}$ if circuit q is represented in each product by the mutual impedance Z_{qr}.

Effective Impedances of Any Network

In the theoretical discussion of networks we are concerned not so much with particular values of the electromotive forces and currents, as with their relative values. For this reason the impedances, which are the ratios of electromotive forces to currents, and the attenuation factors, which are either the ratios of currents to each other, or of electromotive forces to each other, are chosen as the immediate objects of investigation.

Effective impedances may be defined in various ways, for example as:

$$(a)\quad \frac{\text{potential of point } s_j \text{ minus potential of point } s_k}{\text{current at point } s_l},$$

$$(b)\quad \delta\,\frac{\text{power taken by any part } S_o \text{ of network}}{\text{product of currents at points } s_q \text{ and } s_r},$$

($\delta = 1$ or $\frac{1}{2}$ for self and mutual impedances respectively.)

$$(c)\quad \frac{1}{\delta}\,\frac{\text{product of potential differences points } s_t,\ s_u \text{ and } s_v,\ s_w}{\text{power taken by any part } S_x \text{ of network}}$$

($\delta = 1$ or $\frac{1}{2}$ for self- and mutual impedances respectively.)

(*d*) The impedances required to make a normal type of network of the requisite number of parameters equivalent to the given network under specified conditions of operation.

As examples of the above definitions we may instance the following:

The mutual impedance of a transformer is the ratio, with sign reversed, of the electromotive force induced in either winding to the inducing current flowing in the other winding, which falls under definition (*a*) if the secondary is first open-circuited.

In discussing below the power taken by the actual resistances in a network use is made of definition (*b*) in formula (**26**).

The expression, formula (**10**), for the total power taken by a network in terms of the impressed forces, gives, on breaking up the expression into its individual terms, a set of self-impedances and mutual impedances defined in accordance with definition (*c*).

As an example of definition (*d*) we may take the important case where we are concerned only with two accessible circuits in a network and wish to replace the given network by a normal type having only the required three complex parameters. The normal networks which are ordinarily employed are the " T ", the " Π," the transformer and the artificial line and for these the effective impedances are given in table I, together with the simple circuit impedances which equal the driving point impedance in either circuit S_q and S_r and the driving-driven point impedance S_{qr} of a single circuit which would give the electromotive force ÷ current ratio actually obtaining when the electromotive force is inserted in q (or r) and the current is measured in r (or q). J_q, J_r, J_{qr} are called the primary, secondary and mutual impedances as they correspond to the primary self-inductance, secondary self-inductance, and mutual inductance following established scientific usage. This terminology is employed throughout this paper, as its extension to three or more circuits is obvious and symmetrical, and it seems to be the only logical system. Many electrical engineers, however, call H_q, H_r, H_{qr}^{-1} (H_{qr} being taken with inductive reactance) the primary impedance, secondary impedance and primary admittance, in case the assumed ratio of turns is 1 to 1.

The table refers to the general case where the two circuits are not symmetrical, but the formulæ are in such form as to facilitate reduction to the special case of symmetrical circuits. In this table different letters are employed for the various effective impedances thus somewhat reducing the multiplication of subscripts.

ELIMINATION OF CONCEALED CIRCUITS

In general we may divide a network into a concealed and an accessible part and it is convenient to eliminate the former from explicit appearance in the impedance determinant A when we are concerned only with the effects which are produced in the accessible part of the network due to causes which are likewise confined to this part of the network.

Elimination of a group of concealed circuits (or of any circuits which contain no impressed forces) from explicit appearance in A is equivalent to the substitution of new effective impedances

$$J_{qr}=\frac{A_{\frac{\alpha}{qr}}}{A_{\alpha}}$$

between accessible circuits q and r where α stands for the product of the original self-impedances of the accessible circuits.

To prove this we notice that the set of Kirchhoff electromotive force equations for the concealed circuits taken alone give

$$I_c = \frac{1}{A_\alpha} \sum_r I_r A_{\frac{\alpha.xc}{xr}} \quad \text{where} \begin{cases} c = \text{any concealed circuit} \\ r = \text{any accessible circuit} \\ x = \text{any circuit} \end{cases}$$

which substituted in the electromotive force equation for any accessible circuit q make the new coefficient of I_r in this equation

$$J_{qr} = Z_{qr} + \frac{1}{A_\alpha} \sum_c Z_{qc} A_{\frac{\alpha.qc}{qr}} = \frac{1}{A_\alpha} \left[Z_{qr} A_{\left(\frac{\alpha}{qr}\right)qr} + \sum_c Z_{qc} A_{\left(\frac{\alpha}{qr}\right)qc} \right]$$

after setting $x = q$

$$= \frac{A_{\frac{\alpha}{qr}}}{A_\alpha} = \frac{A_{\frac{\alpha}{rq}}}{A_\alpha} = J_{rq}, \text{ as } A \text{ is symmetrical.} \tag{12}$$

J_{qr} is thus the new effective mutual impedance (or self-impedance if $q = r$) between accessible circuits q and r.

In the important case where all but two of the circuits are eliminated, we have

$$J_{qq} = \frac{A_{rr}}{A_{qq \cdot rr}}$$

$$J_{rr} = \frac{A_{qq}}{A_{qq \cdot rr}} \tag{13}$$

$$J_{qr} = \frac{-A_{qr}}{A_{qq \cdot rr}}$$

And if but one circuit q is regarded as accessible, the driving point impedance of the network to an electromotive force inserted in that circuit, is

$$J_{qq} = \frac{A}{A_{qq}} \tag{14}$$

If we eliminate the circuits corresponding to all of the branch points and to an equal number of the branches which are connected to these branch points but do not form any closed circuit among themselves, it may be shown that: $A_\alpha = 1$; the new effective impedances are equal to sums and differences of the original impedances with coefficients which are 0, ±1, or ±2; the circuits which are not eliminated are equal in number to the degrees of freedom of the network. The case falls under that directly derived above by the use of circuital currents.

If $A_\alpha = 0$ the method of elimination fails, which shows that whenever fictitious branch point circuits are eliminated at least one branch connected to each branch point must be included and that the number of closed circuits formed by the branches must not be greater than the excess of eliminated branches over eliminated branch points.

No change is made in the effective self- or mutual impedance of an accessible circuit q by the elimination of circuits which have no mutual impedance with circuit q. That is $A_{\frac{\alpha}{qr}} = Z_{qr} A_\alpha$ since the added q row has but one term Z_{qr} which differs from zero.

A concealed branch of admittance Y which is free from mutual impedances may be eliminated by adding Y to each of the two self-impedances and subtracting Y from the mutual impedance of the two fictitious circuits which replace the terminal branch points of the concealed branch. Any number of concealed branches may be eliminated in this way; the total self-impedance added to any fictitious circuit will equal the total admittance of the eliminated branches terminating at the corresponding branch point; the total mutual impedance subtracted between any two fictitious circuits will equal the total admittance eliminated between the corresponding branch points.

To prove, let the concealed branch impedance be $Z = 1 \div Y = A_\alpha$, then, if the self- and mutual-impedances of the fictitious circuits corresponding to the terminals of this branch are originally Z_1, Z_2 and Z_{12}, they become after the elimination of the concealed branch

$$J_1 = \frac{A_{\frac{\alpha}{11}}}{A_\alpha} = Y \begin{vmatrix} Z_1 & \pm i \\ \pm i & Z \end{vmatrix} = Z_1 + Y$$

$$J_2 = \frac{A_{\frac{\alpha}{22}}}{A_\alpha} = Y \begin{vmatrix} Z_2 & \mp i \\ \mp i & Z \end{vmatrix} = Z_2 + Y$$

$$J_{12} = \frac{A_{\frac{\alpha}{12}}}{A_\alpha} = Y \begin{vmatrix} Z_{12} & \pm i \\ \mp i & Z \end{vmatrix} = Z_{12} - Y$$

Any concealed part of a network connected to the remainder of the network through a group of terminals (branch points) $q, r, s, \ldots$ ***only*** (and having the impedance determinant A_α or A_β according as the concealed part is taken alone or is taken together with the circuits corresponding to the group of accessible terminals) ***may be replaced by any one of the following***:

(*a*) Self-impedances $A_{\frac{\alpha}{qq}} \div A_\alpha$ and mutual impedances $A_{\frac{\alpha}{qr}} \div A_\alpha$ added to the fictitious circuits corresponding to the group of terminals.

(*b*) Branches, devoid of mutual impedance, connecting the group of terminals in pairs and having the admittances $-A_{\frac{\alpha}{qr}} \div A_\alpha$. These admittances we will call the equivalent direct admittances of the network.

(*c*) Branches radiating from a common concealed point, one to each of the terminals, with self-impedances $A_{\beta.qq} \div A_\beta$ and mutual impedances $A_{\beta.qr} \div A_\beta$.

(*d*) Branches radiating from a common concealed point, one to each of the group of terminals, these branches being devoid of self-impedance and having mutual impedances $-(A_{\beta.qq} + A_{\beta.rr} - 2\,A_{\beta.qr}) \div 2\,A_\beta$.

(*e*) Branches connecting any one of the terminals q to each of the remaining accessible terminals $r, s, \ldots,$ the branch connected to terminal r having the self-impedance $(A_{\beta.qq} + A_{\beta.rr} - 2\,A_{\beta.qr}) \div A_\beta$ and the mutual impedance $(A_{\beta.qq} + A_{\beta.rs} - A_{\beta.qr} - A_{\beta.qs}) \div A_\beta$ to the branch connected to terminal s.

Substitution (*a*) is a restatement of the results previously established for the case of concealed and accessible parts which are not connected the one to the other by mutual impedances.

To show that (*b*) is equivalent to (*a*) apply to (*b*) the theorem for eliminating concealed branches which are devoid of mutual impedances; the fictitious circuits corresponding to the group of terminals will thereby have their mutual impedances increased by $A_{\frac{\alpha}{qr}} \div A_\alpha$ and their self-impedances increased by

$$-\frac{1}{A_\alpha}\sum_{r(\neq q)} A_{\frac{\alpha}{qr}} = \frac{1}{A_\alpha}\left(A_{\frac{\alpha}{qq}} - \sum_{r} A_{\frac{\alpha}{qr}}\right) = A_{\frac{\alpha}{qq}} \div A_\alpha$$

since the complete summation with respect to r of the bordered determinants $A_{\frac{\alpha}{qr}}$ equals the determinant A_α bordered by the row q and a column equal to the sum of all of the fictitious circuit columns r, and vanishes since terms $+i$ and $-i$ occur in pairs and cancel, making the column identically equal to zero. Substitution (*b*) having been transformed into substitution (*a*) the two are mutually equivalent.

Substitutions (*c*), (*d*) and (*e*) are readily shown to be mutually equivalent to each other and to the original network by showing that the impedance between any two terminals u and v with all others insulated is $(A_{\beta.uu}+A_{\beta.vv}-2A_{\beta.uv})\div A_{\beta}$.

The direct admittance between two terminals of any network, as defined under (*b*), is equal to one-half of the excess of the grounded admittance of the two terminals taken separately over their grounded admittance when taken together as a single terminal. By the grounded admittance of a terminal is understood the admittance between that terminal and ground with all of the other terminals grounded. As grounded admittance can be readily measured with simple apparatus, this always affords one method of experimentally determining the direct admittance in any network.

COMPLETE ELIMINATION OF EITHER MUTUAL IMPEDANCES OR SELF-IMPEDANCES

It has been shown [(*b*) and (*d*) above] that if we retain a group of terminals as the only accessible part, any network may be replaced either by a set of direct impedances connecting the terminals in pairs, or by a set of mutual impedances between branches radiating from a common point and terminating one at each of the terminals. In the first case all mutual impedances are avoided; in the second case all self-impedances are avoided. Applications to the simple transformer are of interest as showing that in these substitutions an open circuit is taken care of either by parallel self-impedances which are equal but of opposite signs or by infinite mutual impedances differing by finite amounts. The substitutions show that a transformer J_1, J_2, J_{12}, is equivalent to either

(*a*) The six-branch network directly connecting the four terminals, the impedances of which are

$$\frac{J_1 J_2 - J_{12}^2}{J_2},\quad \frac{J_1 J_2 - J_{12}^2}{J_1},\quad \frac{J_1 J_2 - J_{12}^2}{J_{12}},\quad -\frac{J_1 J_2 - J_{12}^2}{J_{12}} \tag{15}$$

between the primary terminals, the secondary terminals, each of the two pairs of correspondingly poled terminals of primary and secondary and each of the two pairs of non-corresponding terminals of primary and secondary, respectively. (In Figs. 6 and 7 terminals 1-2, 3-4, 1-3, and 2-4, 1-4 and 2-3 respectively.)

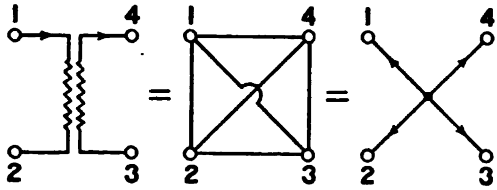

FIG. 6 FIG. 7 FIG. 8
Transformer and equivalent networks having four accessible terminals

Or (*b*) the four-branch network connecting the four terminals to a concealed common point, the mutual impedances being

$$-\frac{J_1}{2}, -\frac{J_2}{2}, \infty + \frac{J_{12}}{4}, \infty - \frac{J_{12}}{4} \tag{16}$$

between the branches (taken with their positive directions diverging from the common point) which terminate at the same pairs of terminals as for case (*a*), respectively. See Figs. 6 and 8.

In certain cases a mutual impedance may be eliminated by properly augmenting the impedances of not more than four branches, without altering the arrangement of branches in any way or imposing any restriction as to whether they are concealed or accessible. These cases are all included under that of mutual impedance between diagonally opposite branches of a generalized bridge, by which we will understand a network differing from the ordinary bridge only in having the four bridge corners replaced

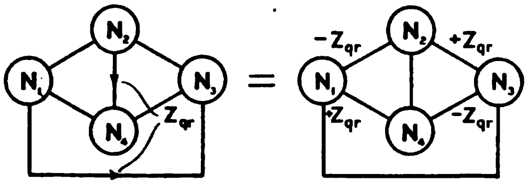

FIG. 9 FIG. 10
Generalized bridge with equivalent mutual and self impedances

by four arbitrary networks; these corner networks may have mutual impedances between one another, but the only branches connecting them are to be the six branches corresponding to the simple bridge. *Mutual impedance between diagonally opposite branches in the generalized bridge is replaceable by an equal amount* *of self-impedance in each of the four bridge-arms, added to or subtracted from the original self-impedance of the arm, according as the arm connects the branches having the mutual impedance with their positive directions concurrent or opposed.* (Figs. 9 and 10.) An important special case is that in which one arm of the bridge is open-circuited and the network reduces to three branches connecting two arbitrary networks otherwise unconnected except possibly by mutual impedances. (Figs. 11 and 12.)

The correctness of the substitution is shown by the fact that the impedance of every closed circuit is the same before and after the substitution, and that this is the most general case is proven by noticing: (1), that the generalized bridge becomes an unrestricted network by admitting any number of branches connecting the four corner networks in pairs; and (2), that with a single branch added to Figs. 9 and 10, it is impossible to keep the self-impedance of every closed circuit the same in the two cases, for the added branch requires different increments according to the circuit through which it is closed.

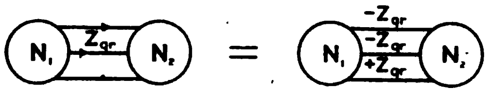

FIG. 11 FIG. 12

Three-branch connection with equivalent mutual and self impedances

In the simple bridge circuit there are 15 possible mutual impedances which may be eliminated by taking as the effective branch impedances the six permutations of

$$Z_{12}' = Z_{12} + Z_{12,23} + Z_{12,24} + Z_{12,31} + Z_{12,41} + Z_{13,14} + Z_{23,24} + Z_{13,42} + Z_{14,32} \qquad (17)$$

where 1, 2, 3, 4 stand for the bridge corners. The condition for a balance of the bridge arms 12, 23, 34, 41 is therefore always

$$Z_{12}' Z_{34}' = Z_{23}' Z_{41}' \qquad (18)$$

IMPEDANCE LOCI

It is often of importance to know how the impedances of a network will vary if the self-impedances or mutual impedances of one or more of the branches of the network are varied over lines or areas in any physically possible manner. On account of the magnitude of this subject we shall touch on the simplest case only, namely that of the driving point impedance with a variable impedance added to one branch of the network.

As the discriminant A and its minors are of the first degree in terms of each self-impedance which they contain, it follows that the effective impedances of the network, being equal to the quotient of two of these determinants, are bilinear functions of the individual impedances; thus the driving point impedance of a network at circuit q is connected with a self-impedance Z inserted in any circuit r by a relation of the form

$$S_q = \frac{a\,Z+b}{c\,Z+d} \tag{20}$$

where a, b, c and d are constants.

The property of the bilinear transformation which is of special importance to us is that it transforms circles into circles, that is, if Z be regarded as a variable and be made to traverse any circle whatsoever, the driving point impedance S will also describe a circle. In making this statement the straight line is included as the limit of a circle so that the loci of S and Z may be straight lines as well as circles. This property of the bilinear transformation is discussed at length in the theory of analytic functions and need not be entered into here.

We are especially concerned with the cases where the locus of Z is a straight line such as the axis of reals or the axis of imaginaries, because the first is a variation which it is convenient to make use of in practical measurements and the second forms the extreme boundary realizable with physically possible values of the inserted impedance. We shall find it better to replace the constants a, b, c and d by others, such as the effective transformer impedances or the effective line constants, which have a physical significance.

A network having effective transformer constants J_1, J_2, J_{12} effects the transformation of the half of the Z—plane on the positive side of the reactance axis into the area bounded by a circle with center at Z_i and radius R_i:

$$Z_i = J_1 - \frac{J_{12}^2}{J_2+J_2'}, \qquad R_i = \frac{|J_{12}^2|}{J_2+J_2'} \tag{21}$$

the axis of reals going over into the circumference of a circle having its center at Z_r *and radius* R_r:

$$Z_r = J_1 - \frac{J_{12}^2}{J_2 - J_2'}, \qquad R_r = \frac{|J_{12}^2|}{|J_2 - J_2'|} \tag{22}$$

where J_2' *is the conjugate of* J_2 *and* $|J_{12}^2|$ *the modulus of* J_{12}^2. *The two circles cut each other orthogonally at* J_1 *and* $(J_1 - J_{12}^2 \div J_2)$ *which correspond to open and short-circuited secondary. The double points = effective line impedances (far end with sign reversed) are*

$$\left.\begin{matrix} K_1 \\ -K_2 \end{matrix}\right\} = \frac{J_1 - J_2}{2} \pm \tfrac{1}{2}\sqrt{(J_1 + J_2)^2 - 4J_{12}^2} \tag{23}$$

Proof: Close the secondary through the added impedance $Z\,x$, where x is a real variable, and the effective driving point impedance at the primary is

$$S_1 = \frac{J_1(J_2 + Zx) - J_{12}^2}{J_2 + Zx} = J_1 - \frac{J_{12}^2}{J_2 + Zx} \; \frac{Z'(J_2 + Zx) - Z(J_2' + Z'x)}{J_2 Z' - J_2' Z} \tag{24}$$

$$= \left(J_1 - \frac{J_{12}^2 Z'}{J_2 Z' - J_2' Z}\right) + \left(\frac{J_{12}^2 Z}{J_2 Z' - J_2' Z}\right)\left(\frac{J_2' + Z' x}{J_2 + Zx}\right) \tag{25}$$

and in this form the expression obviously represents a circle, of which the center is the first term, and the radius the modulus of the last term, since the variable x occurs only in the last factor of the last term and variations in x change the angle but not the modulus of this factor as its numerator is the conjugate of its denominator. If $Z = -Z' = i$, the inserted impedance is pure imaginary and we obtain from (**25**) the constants for the boundary circle as given in (**21**). If $Z = Z' = 1$, the added impedance is real and the effective driving point impedance falls on a circle with the constants as given in (**22**). To determine the double points substitute $Zx = S = K$ in the first part of (**24**) and solve the resulting quadratic in K which gives the values (**23**).

As a practical example of impedance loci, consider Fig. 13, which shows the driving point impedance of a transmission line for a frequency of 1,300 cycles per second, the line containing 6.201 wave lengths, presenting an attenuation constant of 0.9123 and having line impedances $K_1 = 1762 - 191i$ and $K_2 = 1614 - 781i$ for transmission from the driving point to the receiving end and vice versa. The driving point impedances actually measured are the points marked by circles near a, b, c and d for which the far end of the line was closed through a short circuit,

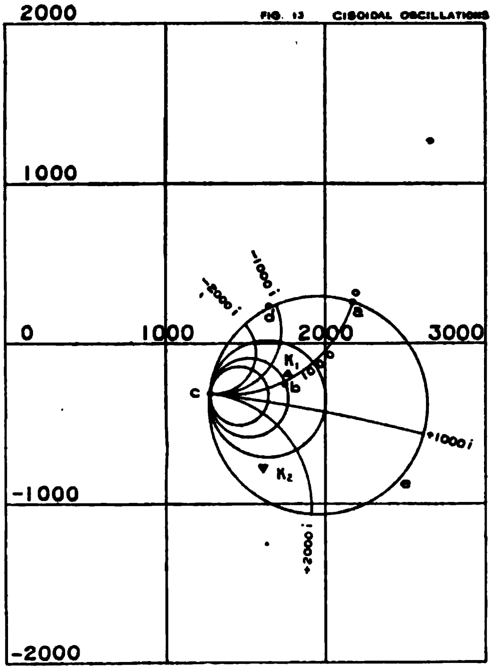

FIG. 13.—Bilinear transformation for a line containing 6.201 wave lengths and having the attenuation constant 0.9123 and the line impedances $K_1 = 1762 - 191\,i$ and $K_2 = 1614 - 781i$ which maps the half plane on the positive side of the imaginary axis into the circle $a\ d\ c\ e$ with the rectangular ruling mapping into the orthogonal system of circles.

through 2,000 ohms, through an open circuit and through a capacity of 0.107 mf. respectively. As but three measurements are necessary in order to completely determine the three bilinear constants, it was necessary to adjust the four observations to the most probable bilinear transformation. It will be seen that the corrections which it was necessary to apply to the observations were small, being in fact well within the errors of observation. The circle *a d c e* corresponds to the entire imaginary axis of Z; the arc *a b c* corresponds to the entire positive axis of Z. Circles are also shown corresponding to values of Z having constant real components of 1,000, 2,000 and 3,000 ohms and constant imaginary components of ±1,000 and ±2,000 ohms. The line impedances K_1 and K_2 are also shown. As the particular line under measurement effects the transformation of the rectangular network shown in Fig. 13 into the orthogonal system of circles, the diagram shows that the driving point impedance has the resistance limits 1,270 to 2,640 ohms and the reactance limits $-$ 1,070 to +300 ohms. The diagram as it stands is sufficiently complete to permit of reading off approximately the value of the driving point impedance for any value of the impedance Z bridged at the receiving end of the line.

The following construction will be required below and may be proven here.

The effective joint impedance S of two impedances Z_1, Z_2 in parallel coincides with the intersection of the circles which are tangent to these impedances at the origin and have the individual impedances as chords. This construction follows at once from the circular locus of S for variable modulus of either Z_1 or Z_2 and the fact that if one of the parallel impedances Z_1 vanishes or the other impedance Z_2 becomes infinite the joint impedance is equal to Z_1. This construction is employed in Fig. 15 for obtaining S from Z_1 and Z_2 or vice versa.

DIVISION OF POWER BETWEEN THE RESISTANCES AND REACTANCES OF A NETWORK

The total power taken by a network is the sum of the powers taken by the individual self-impedances and mutual impedances, and to determine the division of this power between parts of the network it is merely necessary to find the summations for each part separately. As the total power and all of its components are directly proportional to the square of the current entering the network at the driving point, it is more convenient to consider, as the immediate object of discussion, the effective impedances which are defined as the ratios of the powers to the driving current squared. Accordingly we shall discuss the effective impedances S, U, $V\,i$ which correspond respectively to the total powers taken by the entire network, by the true resistances alone, and by the reactances alone. From this definition of these impedances it follows that

$$S = U + Vi = \sum_{j=1}^{n} \sum_{k=1}^{n} Z_{jk} \frac{I_j I_k}{I_d^2} = \sum_{j=1}^{n} Z_j \left(\frac{I_j}{I_d}\right)^2 + 2 \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} Z_{jk} \frac{I_j I_k}{I_d^2},$$

$$U = \sum_{j=1}^{n} \sum_{k=1}^{n} R_{jk} \frac{I_j I_k}{I_d^2}, \qquad \text{where } Z_{jk} = R_{jk} + i\,X_{jk} \qquad (26)$$

$$Vi = i \sum_{j=1}^{n} \sum_{k=1}^{n} X_{jk} \frac{I_j I_k}{I_d^2}.$$

The impedance U corresponding to the power taken by the resistances in the general passive network may have any argument, and any modulus which is not greater than the effective resistance of the network. To prove:

Consider an ideal line of zero attenuation containing s wave lengths, closed at the far end through a resistance equal in value to the line impedance K, with an impedance $(R - K) + Bi$ in series at the sending end so as to make the total impedance at the sending end equal to $R + Bi$. A current I flowing at the sending end gives rise to a current I cis $(-2\pi s)$ at the receiving end so that the total power taken by the resistances is

$$P = (R - K)\, I^2 + K\, I^2 \text{ cis } (-4\pi s)$$

Therefore

$$U = (R - K) + K \text{ cis } (-4\pi s)$$

an impedance which may obviously assume any argument and any modulus not exceeding R with positive real values of K, $(R - K)$, and s.

The modulus of U can under no circumstances be greater than the effective resistance of the network for if this were the case the correlated sinusoidal oscillation would have, at some part of each oscillation, a negative total consumption of power by the resistances which is obviously impossible when the network contains neither sources of power nor so-called negative resistances, which are excluded throughout this discussion.

In Fig. 14 S and R represent the effective driving point impedance and the effective driving point resistance of the network, while U and Vi show a possible resolution of the impedance S into components corresponding to the powers taken by the true resistances and the reactances respectively. The circle $R\,b\,c\,d$ drawn about the origin with $O\,R$ as a radius is the maximum possible locus of U. If U falls at point b or d the power taken by the reactances has its maximum or its minimum value. If U falls at R the power taken by the reactances is 90 degrees ahead of the power taken by the resistances and this case corresponds to the series arrangement of a resistance and a reactance. (This is for positive reactance; with negative reactance the lead becomes a 90 degree lag.) At point c the relative phases are reversed, the resistances taking power 90 degrees in advance of that taken by the reactances; this case, as follows from the formulæ deduced below for parallel circuits, may be realized theoretically by the association of a pure resistance and a pure positive reactance in parallel. The point of special interest is the origin O; if U vanishes the cisoidal powers taken by the various resistances cancel each other in the summation for the resultant; in the correlated sinusoidal oscillation the power taken by the resistances is constant, that is the total generation of heat in the network does not fluctuate during an oscillation. This would seem to be a property which might have practical application.

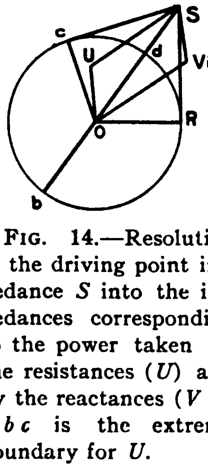

FIG. 14.—Resolution of the driving point impedance S into the impedances corresponding to the power taken by the resistances (U) and by the reactances ($V\,i$); $R\,b\,c$ is the extreme boundary for U.

If λ_1, λ_2, are the maximum and minimum driving point impedance arguments obtainable from the elements employed in a network of driving point impedance $S=R+Xi=|S|\operatorname{cis}\sigma$ the impedance U must lie in the lenticular area common to the two circles which intersect at the effective resistance of the network (R) and are centered at the projections of S on lines drawn through the origin at the angles ($\sigma-\lambda_1$) and ($\sigma-\lambda_2$).

Multiply each impedance Z_{jk} in the network by cis $\left(\frac{\pi}{2}-\lambda\right)$. As this leaves the current ratios unchanged the new value of U will be

$$\underline{U}=\sum\sum|Z_{jk}|\cos\left(\frac{\pi}{2}-\lambda+\sigma_{jk}\right)\frac{I_j I_k}{I_d^2}$$

$$=i\cos\lambda\sum\sum|Z_{jk}|\ \text{cis}\ \sigma_{jk}\ \frac{I_j I_k}{I_d^2}$$

$$-\,i\ \text{cis}\ \lambda\sum\sum|Z_{jk}|\cos\sigma_{jk}\ \frac{I_j I_k}{I_d^2}$$

$$=i\,S\cos\lambda-i\,U\ \text{cis}\ \lambda$$

Therefore $U=i\,\underline{U}\ \text{cis}\ (-\lambda)+S\cos\lambda\ \text{cis}\ (-\lambda)$

which expresses the actual value of U in terms of the modified value $\underline{U}$. We may make $\lambda=\lambda_1$ without introducing any resultant negative resistance in the network, for the multiplication of each impedance by cis $\left(\frac{\pi}{2}-\lambda_1\right)$ raises the maximum argument from λ_1 to $\pi\div 2$. The extreme possible boundary limit for U will then be the circle of radius equal to the new effective resistance or

$$\text{Extreme limit for } \underline{U}=|S|\cos\left(\sigma+\frac{\pi}{2}-\lambda_1\right)\ \text{cis}\ \mu$$

$$=|S|\sin(\lambda_1-\sigma)\ \text{cis}\ \mu$$

where μ is any real angle.
Substituting this in the above equation, we obtain as a necessary condition

$$\text{Limit for } U=|S|\cos\lambda_1\ \text{cis}\ (\sigma-\lambda_1)+i|S|\sin(\lambda_1-\sigma)\ \text{cis}\ (\mu-\lambda_1)$$

Since the only variable is the unrestricted real quantity μ this locus for U is the circle of which the center is the first term and the radius the modulus of the second term. The first term is the point at the foot of the perpendicular let fall from the extremity of S on the line cis $(\sigma-\lambda_1)$ and the distance from this point to the extremity of R is $||S|\cos\sigma-|S|\cos\lambda_1\ \text{cis}\ (\sigma-\lambda_1)|$ $=|S||\text{cis}-\lambda_1||\cos\sigma\ \text{cis}\ \lambda_1-\cos\lambda_1\ \text{cis}\ \sigma|=|S\sin(\lambda_1-\sigma)|$, the modulus of the second term.

The corresponding proof for the minimum limit is made by substituting $-\left(\frac{\pi}{2}-\lambda_2\right)$ for $\left(\frac{\pi}{2}-\lambda\right)$. That the lenticular area thus defined is a sufficient as well as necessary restriction is proven by the properties of parallel circuits discussed below.

We may note that U cannot vanish unless there is a range of at least 90 degrees in the impedances of the elements entering the network.

All possible distributions of power between the resistances and the reactances, with any given total driving point impedance may be obtained from two reactive resistances in parallel, and it will now be of interest to examine this case in detail. We will assume that the impedances Z_1, Z_2, when connected in parallel are to have a given total effective impedance S and a given impedance U corresponding to the total power taken by the resistances. These conditions give

$$S=\frac{Z_1 Z_2}{Z_1+Z_2}$$

$$U=\frac{Z_1+Z_1'}{2}\left(\frac{Z_2}{Z_1+Z_2}\right)^2+\frac{Z_2+Z_2'}{2}\left(\frac{Z_1}{Z_1+Z_2}\right)^2$$

$$=\frac{(Z_1 S'-Z_1' S)^2}{2\,Z_1^2\,(Z_1'-S')}+\frac{S+S'}{2} \qquad (27)$$

where the first expression for U is in terms of the resistances and current ratios and the second expression is found by substituting for Z_2 its value in terms of Z_1 and S.

$$\left.\begin{aligned} \text{Let } F&=|F|\text{cis}\,\varphi=U-\frac{S+S'}{2}\\ S&=|S|\text{cis}\,\sigma\\ Z&=|Z|\text{cis}\,\theta \end{aligned}\right\} \qquad (28)$$

and put the last expression for U in the form

$$2\,F\,Z^2\,(Z'-S')=(Z\,S'-Z'\,S)^2=-\,4|Z^2\,S^2|\sin^2(\theta-\sigma)$$

where subscripts are omitted as the equation applies equally to Z_1 and Z_2. Taking the imaginary part of this equation before and after multiplying by cis $(-\theta-\varphi)$ we have, after dropping the common factors $2|FZ^2|i$ and $2|Z^2S|\sin(\theta-\sigma)\,i$,

$$|Z|\sin(\theta+\varphi)-|S|\sin(2\theta-\sigma+\varphi)=0$$

$$-|F|=2|S|\sin(\theta-\sigma)\sin(\theta+\varphi)=|S|[(\cos(\sigma+\varphi)-\cos(2\theta-\sigma+\varphi)]$$

$$\text{therefore } Z=|S|\frac{\sin(2\theta-\sigma+\varphi)}{\sin(\theta+\varphi)}\text{ cis }\theta \qquad (29)$$

with values of θ given by

$$\cos(2\theta-\sigma+\varphi)=\cos(\sigma+\varphi)+|F\div S|$$

which is the required solution for Z_1 and Z_2.

The graphical construction for determining S and U when Z_1 and Z_2 are given, or vice versa, are sufficiently simple to be of assistance. The construction rules which are readily deducible from the preceding work are as follows:

Given Z_1 and Z_2 to find S and. U, Fig. 15. Find the impedance S of Z_1 and Z_2 in parallel and draw the circle having S as a diameter, on this circle locate points d_1 and d_2 so that arc $S\,d_1=$ arc $c_1\,R$, and arc $S\,d_2=$ arc $c_2\,R$ where c_1, c_2 and R are the intersections of the circle with Z_1, Z_2, and the resistance axis, using d_1 and d_2 as centers strike circles passing through point R. The other intersection of the circles is the effective impedance U.

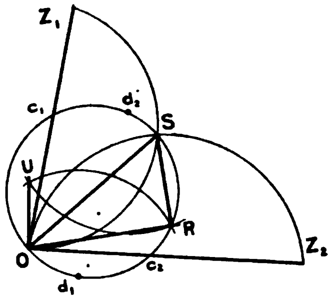

FIG. 15.—Graphical construction for determining the effective driving point impedance (S) and the effective impedance corresponding to the power taken by the resistances (U) for two impedances Z_1 and Z_2 in parallel.

Given S and U to find Z_1 and Z_2. Find the intersections d_1 and d_2 of the circle having S as a diameter and the normal right line bisecting $U\,R$, lay off arc $c_1\,R=$ arc $S\,d_1$, and arc $c_2\,R=$ arc $S\,d_2$. Then $O\,c_1$ and $O\,c_2$ are the direction lines for Z_1, Z_2 the magnitude of which are found by the intersection therewith of the circles tangent to $O\,c_1$ and $O\,c_2$ which have $O\,S$ as a chord.

The vanishing of U requires a difference of 90 degrees in the two impedances Z_1 and Z_2; if the driving point impedance S is to be pure resistance $(=R)$ we have the important case where the parallel impedances are $(R\pm R\,i)$.

FREE OSCILLATIONS

The characteristic feature of free oscillations is that, throughout the part of the network over which the oscillation extends, the driving point impedance is equal to zero. This follows from the fact that as the driving point impedance is equal to the impressed electromotive force divided by the current, it vanishes when the electromotive force vanishes, provided the current does not vanish. The criterion for free oscillations is therefore

$$A = O \tag{30}$$

The solution of this equation contains all of the possible values of the time coefficient p. Each possible oscillation is aperiodic or not according as p is pure imaginary or not; p cannot be real for any actual system, since energy must be dissipated in any oscillation which may occur in such a system.

In present day practical applications, complex or imaginary values of p occur, as a rule, only for free vibrations; but there is no inherent reason why such vibrations should not arise as forced vibrations, for that requires only that an alternator be used which gives an electromotive force of constant period and logarithmically decreasing amplitude. This condition is approximately realized by a freely vibrating system which is loosely coupled to the network under consideration.

As an illustration of the application of the method to free oscillations, determine the time coefficients (*i.e.*, the free periods and associated damping constants) for two coupled circuits of impedances Z_1, Z_2, Z_{12}. For this case

$$\begin{aligned} A = \begin{vmatrix} Z_1 & Z_{12} \\ Z_{12} & Z_2 \end{vmatrix} &= Z_1 Z_2 - Z_{12}^2 = 0 \\ &= [(2\,\delta_1 + p\,i)\,(2\,\delta_1' + p\,i) + p_1^2]\,[(2\,\delta_2 + p\,i)\,(2\,\delta_2' + p\,i) + p_2^2] \\ &\qquad + k^2\,p^2\,(2\,\delta_1' + p\,i)\,(2\,\delta_2' + p\,i) \end{aligned} \tag{31}$$

where $\delta = \dfrac{R}{2\,L}$, $\delta' = \dfrac{G}{2\,C}$, $p = \dfrac{1}{\sqrt{L\,C}}$, $k = \dfrac{M}{\sqrt{L_1\,L_2}}$,

taken with subscripts 1 and 2 to correspond with the circuits. For small damping constants δ, δ' (**31**) may be developed into a series of which the first terms are

$$p\,i = p_0\,i - \frac{\delta_1(p_0^2-p_2^2)+\delta_1'(p_0^2(1-k^2)-p_2^2)+\delta_2(p_0^2-p_1^2)+\delta_2'(p_0^2(1-k^2)-p_1^2)}{2p_0^2\,(1-k^2)-p_1^2-p_2^2}+\dots \tag{32}$$

$$\text{where } p_0 = \sqrt{\frac{p_1^2+p_2^2 \pm \sqrt{(p_1^2-p_2^2)^2+4\,k^2\,p_1^2\,p_2^2}}{2\,(1-k^2)}} \tag{33}$$

are the time coefficients which would obtain if the circuits were free from all dissipative losses.

In the special case of two identical circuits $(Z_1 = Z_2 = Z)$ the determinantal equation becomes $A = (Z+Z_{12})\ (Z-Z_{12}) = 0$

$$\text{or } R+(L\pm M)\,p\,i+\frac{1}{G+C\,p\,i}=0$$

$$\text{whence } i\,p = -\left(\frac{R}{2\,(L\pm M)}+\frac{G}{2\,C}\right)$$

$$\pm i\sqrt{\frac{1}{(L\pm M)\,C}-\left(\frac{R}{2\,(L\pm M)}-\frac{G}{2\,C}\right)^2} \tag{34}$$

without any restrictions as to the values R, L, M, G and C.

INFINITE NUMBER OF CIRCUITS—EDDY CURRENTS.

When the number of circuits is increased indefinitely the determinant A becomes of infinite order. The particular application which at once suggests itself is that of eddy currents in a cylindrical core. Consider the core of radius a as being made up of a large number n of concentric hollow tubes of thickness $a \div n$ and radii $q\,a \div n$, $(q = 1,\ 2,\ \dots\ n)$ and take as the driving winding another tube of radius $(n+1)\ a \div n$ which has infinite conductivity. Then the impedance for tubes q and r per unit of length is

$$Z_{qr}=Z_{rq}=2\,\pi\,\rho\left(\delta_{qr}\,q+2\,z\,i\,\frac{q^2}{n^2}\right),\qquad \begin{array}{l} 1 \leq q \leq r \leq n+1 \\ \delta_{qr} = \begin{cases} 1 \text{ if } q=r<n+1 \\ 0 \text{ in other cases.}\end{cases}\end{array} \tag{35}$$

with $z = \dfrac{\pi\,a^2\,\mu\,p}{\rho} = \dfrac{\mu\,p}{R} = \dfrac{Lp}{4\,\pi\,\rho}$, R and L being the longitudinal resistance $(\rho \div \pi\,a^2)$ of the core per unit length and inductance $4\,\mu\,\pi^2 a^2$ of the driving winding per turn per unit length of core.

The driving point impedance of the winding is, if $x=2zi\div n^2$.

$$S_{n+1}=\frac{A}{A_{n+1,\,n+1}}=2\pi\rho\frac{\begin{vmatrix} 1+x & x & x & \dots & x & x \\ x & 2+2^2x & 2^2x & \dots & 2^2x & 2^2x \\ x & 2^2x & 3+3^2x & \dots & 3^2x & 3^2x \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ x & 2^2x & 3^2x & \dots & n+n^2x & n^2x \\ x & 2^2x & 3^2x & \dots & n^2x & (n+1)^2x \end{vmatrix}}{\begin{vmatrix} 1+x & x & x & \dots & x \\ x & 2+2^2x & 2^2x & \dots & 2^2x \\ x & 2^2x & 3+3^2x & \dots & 3^2x \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ x & 2^2x & 3^2x & \dots & n+n^2x \end{vmatrix}},$$

$$=2\pi\rho\frac{2\,(n+1)!\displaystyle\sum_{k=1}^{n+1}\left(\frac{z\,i}{n^2}\right)^k\frac{(n+k)!}{(k-1)!\,k!\,(n+1-k)!}}{n!\displaystyle\sum_{k=0}^{n}\left(\frac{z\,i}{n^2}\right)^k\frac{(n+k)!}{(k!)^2\,(n-k)!}}$$

the transformation of the determinants into series of powers of $x\div 2=z\,i\div n^2$ is proven to be correct by its being true for $n=1$ and 2 and satisfying the difference equations for the numerator (N_n) and the consecutive values of the denominator (D_{n-2}, D_{n-1}, D_n and D_{n+1})

$$N_n=D_{n+1}-(n+1)\,D_n$$

$$D_n=(2n-1)\,(1+x)D_{n-1}-(n-1)^2D_{n-2}$$

which are obtained by adding $(n+1)\,D_n$ to N_n, that is increasing its last element by $(n+1)$, which becomes D_{n+1} and by expanding D_n according to the last row and column after subtracting therefrom the next to the last row and column. For n = infinite,

$$\left.\begin{aligned}
S &= 2\pi\rho\,\frac{2\sum\limits_{k=1}^{\infty}\dfrac{(z\,i)^k}{(k-1)\,!\,k\,!}}{\sum\limits_{k=0}^{\infty}\dfrac{(z\,i)^k}{(k\,!)^2}} \\
&= 2\pi\rho\,\frac{2\,z\,i+(z\,i)^2+\dfrac{(z\,i)^3}{6}+\;.\;.\;.}{1+z\,i+\dfrac{(z\,i)^2}{4}+\dfrac{(z\,i)^3}{36}\;+\;.\;.\;.} \\
&= 2\,\pi\,\rho\,\frac{-\sqrt{-4\,i\,z}\,J_1\sqrt{-4\,i\,z}}{J_0\sqrt{-4\,i\,z}} \\
&= 4\,\pi\,\rho\,z\,\frac{d}{d\,z}\log J_0\sqrt{-4\,i\,z} \\
&= 4\,\pi\,\rho\,z\,i\left(1+\frac{J_2\sqrt{-4\,i\,z}}{J_0\sqrt{-4\,i\,z}}\right)
\end{aligned}\right\}\qquad(36)$$

which are the well known results expressed in Bessel's functions, To make the formula perfectly general for any driving winding it is necessary only to multiply by the length of the core and the square of the total number of turns in the winding and to add the impedance of the winding which arises externally to the core.

This example shows that certain infinite systems of circuits which are ordinarily solved by partial differential equations may be handled by the general determinantal solution, but of course when transcendental functions are involved, as in the case of eddy currents, the algebraical reduction may introduce some complexity.

Eddy currents in transformer plates give the following results: For a plate of thickness $2a$, width w and axial length l divided into a large number of $2n$ of sheets of equal thickness and surrounded by a close fitting driving winding of a single turn and zero resistance:

$Z_{qr} = Z_{rq} = \frac{2\,\rho\, w\, n}{a\, l} \left(\delta_{qr} + 4\, z\, i\, \frac{q}{n^2}\right)$, $z = \frac{\pi\, a^2\, \mu\, p}{\rho}$, q, r and δ_{qr} as above and the driving point impedance at limit n = infinite is

$$S = \frac{2\,\rho\, w}{a\, l} \sqrt{4\, z\, i}\, \tanh \sqrt{4\, z\, i} \tag{37}$$

SKIN EFFECT

For a cylindrical conductor of radius a, length l and steady current resistance R with close fitting return shell of zero resistance, the conductor being divided into n concentric tubes of equal cross section with circuit q comprising adjacent tubes q and $q+1$:

$$Z_{qr} = Z_{rq} = \frac{\mu\, l\, p\, n}{z} \left(\delta_{qr} + \frac{z\, i}{n\, q}\, \delta'_{qr}\right) \qquad \delta_{qr} = \begin{cases} 2, \text{ if } q = r < n \\ 1, \text{ if } q = r = n \\ -1, \text{ if } q = r \pm 1 \\ 0, \text{ in other cases} \end{cases}$$

$$\text{with } z = \frac{\pi\, a^2\, \mu\, p}{\rho} = \frac{\mu\, p\, l}{R} \qquad \delta'_{qr} = \begin{cases} 1, \text{ if } q = r < n \\ 1 \div 2, \text{ if } q = r = n \\ 0, \text{ in other cases} \end{cases}$$

and the driving point impedance at limit n = infinite is

$$S = -\frac{2\,\mu\, l\, p\, i}{\sqrt{-4\, i\, z}} \frac{J_0 \sqrt{-4\, i\, z}}{J_1 \sqrt{-4\, i\, z}} \tag{38}$$

Details of Proof. Regard each hollow cylindrical tube as concentrated on its mean diameter, while retaining its actual resistance, $\rho\, n\, l \div \pi\, a^2$. This resistance with sign changed will then be the mutual impedance between any two adjacent circuits, as each tube carries the difference between the currents in the two adjacent circuits of which it forms a common part; no other mutual impedances occur, as no other current products enter the expression for the total energy. The self-impedance of the qth circuit is made up of twice this resistance, together with the inductance $l \div q$; the inductance being found by the single turn solenoid formula 4π cross-section ÷ length, the cross section being $a\, l \div 2\sqrt{q\, n}$ and the length (*i.e.*, mean circumference) being $2\,\pi\, a\sqrt{q \div n}$. For the outermost circuit ($q = n$) this impedance is to be divided by two, since its return circuit is of zero resistance and zero thickness. The impedances Z_{qr} are thus, as stated above. After removing the factor $\mu\, p\, l\, n \div z$ from each element of determinants A and A_{nn} and placing $x = z i \div n$, we have

$$S = \frac{A}{A_{nn}} = \lim_{n=\infty} \frac{\mu p l n}{z} \frac{\begin{vmatrix} 2+\frac{x}{1} & -1 & 0 & \dots & 0 & 0 \\ -1 & 2+\frac{x}{2} & -1 & \dots & 0 & 0 \\ 0 & -1 & 2+\frac{x}{3} & \dots & 0 & 0 \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ 0 & 0 & 0 & \dots & 2+\frac{x}{n-1} & -1 \\ 0 & 0 & 0 & \dots & -1 & 1+\frac{x}{2n} \end{vmatrix}}{\begin{vmatrix} 2+\frac{x}{1} & -1 & 0 & \dots & 0 & 0 \\ -1 & 2+\frac{x}{2} & -1 & \dots & 0 & 0 \\ 0 & -1 & 2+\frac{x}{3} & \dots & 0 & 0 \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ 0 & 0 & 0 & \dots & 2+\frac{x}{n-2} & -1 \\ 0 & 0 & 0 & \dots & -1 & 2+\frac{x}{n-1} \end{vmatrix}}$$

$$= \frac{\mu p l}{z} \cdot \frac{\displaystyle \lim_{x=\infty} \sum_{k=0}^{n} \frac{(2n-k)\,(n-1)!}{2\,(k!)^2\,(n-k)!}\, x^k}{\displaystyle \lim_{x=\infty} \frac{1}{n} \sum_{k=0}^{n-1} \frac{n!}{k!\,(k+1)!\,(n-k-1)!}\, x^k}$$

the correctness of the series expansions for the determinants is readily proven for $n=1$ and 2 directly from the determinants and then extended step by step to any value of n by expanding the determinants according to the terms in the last row and column so as to obtain expressions for the denominator (D_n) and the numerator (N_n) in terms of the denominator with different values of n, *viz*:

$$D_n = \left(2+\frac{x}{n-1}\right) D_{n-1} - D_{n-2}$$

$$N_n = \left(1+\frac{x}{2\,n}\right) D_n - D_{n-1} = D_{n+1} - \left(1+\frac{x}{2\,n}\right) D_n = \tfrac{1}{2}\left(D_{n+1} - D_{n-1}\right)$$

which are readily shown, by substituting the above series expressions, to be identically satisfied for all values of n.

Finally replacing x by its value $z\,i \div n$ and passing to the limit, $n=\infty$

$$S = \frac{\mu\,p\,l}{z}\;\frac{\displaystyle\sum_{k=0}^{\infty}\frac{(z\,i)^k}{(k!)^2}}{\displaystyle\sum_{k=0}^{\infty}\frac{(z\,i)^k}{k!\,(k+1)!}}$$

which is identically formula (**38**), as the numerator is the series for $J_0\sqrt{-4\,i\,z}$ and the denominator is the series for $2\,J_1\sqrt{-4\,i\,z} \div \sqrt{-4\,i\,z}$.

SUMMARY

1. The complex exponential function is shown to be, not a symbolic vector representation of the sinusoidal function, but a scalar function of fundamental importance in its own right, and enjoying algebraical power and energy relations as important as those of real functions. In order to emphasize the basic and distinctive character of the complex exponential function, it is given the name "cisoidal oscillation."

2. The correlation between sinusoidal oscillations and cisoidal oscillations is reduced to a few simple rules which cover power as well as currents and electromotive forces.

3. The general law of distribution of currents in any invariable network is shown to be that of stationary dissipation of power.

4. The law of distribution of cisoidal currents in any invariable network is reduced to that of stationary total power, or to the equivalent condition of stationary driving point impedance or admittance.

5. The cisoidal power is employed as the most convenient means for investigating the division of the instantaneous power between the resistances and reactances of a network.

6. The general solution for cisoidal oscillations in any invariable network is given in determinantal form and it is shown how the various impedances of any particular network may be written down at once and how the elimination of concealed circuits, mutual impedances or self-impedances may be accomplished. Applications to impedance loci, free oscillations and infinite systems of circuits are also given.

DISCUSSION ON "CISOIDAL OSCILLATIONS," LOS ANGELES, APRIL 25, 1911.

C. L. Cory: In order to obtain a physical and in fact practical conception of the results obtained by Mr. Campbell as treated mathematically in his paper, it may be well to consider one of the comparatively simple conditions existing in a circuit containing resistance R and inductance L, there being applied to this circuit an electromotive force having an instantaneous value e, which varies with time t.

In such a circuit the equation which expresses the value of the instantaneous electromotive force, interpreting the equation physically rather than expressing it mathematically, is that the instantaneous electromotive force e applied to such a circuit is expended in two ways; first, to overcome the resistance of the circuit or $R\,i$; and second, to overcome the electromotive force of self-induction in the circuit or $L\,\frac{d\,i}{d\,t}$.

Mathematically such an equation would be as follows:—

$$e=R\,i+L\,\frac{d\,i}{d\,t}.$$

Even with such a comparatively simple equation it can not be solved to give us practical results unless we know or assume the law by which the electromotive force varies with time. However, practically we assume a sine function of the time, and we therefore have: $e=E\sin w\,t$, in which E is the maximum value of the electromotive force and w is equal to $\frac{2\,\pi}{T}$, where T is the time of a complete period.

Instead of having circuits containing resistance R and self-induction or inductance L, only, as we well know, we may have a circuit which contains resistance and electrostatic capacity, or a more complex circuit which contains resistance, inductance and capacity, or a still more complex condition of the circuit or network which contains resistance, inductance, capacity and mutual inductance.

The mutual induction in a circuit can, however, very readily be represented by an equivalent self-induction.

If a variable electromotive force is applied to any of the above circuits and we assume that such electromotive force varies as a sine function of the time, and we solve for the practical values or virtual or effective current and electromotive force, as well as equivalent resistances, reactances and impedances, we get what mathematically is known as the constant of integration. It is this constant of integration which Mr. Campbell has so beautifully and completely treated in his paper. Let us discuss from a strictly physical standpoint this constant of integration.

In an ordinary alternating current circuit we know that if we could succeed in opening or closing such a circuit at the instant when the current is passing through its zero value practically we would get no arc or, except for causing a cessation or establishing the current, we would not introduce electrical disturbances in the circuit. It is of course practically impossible to make and break circuits at exactly the instant when the current value is zero, and as a result if we close or open a switch in an alternating current circuit containing resistance, self-induction, capacity or mutual induction, which may be made the equivalent in self-induction, we produce disturbances or oscillations in such a circuit over which we have practically no control as compared with the fundamental sine wave of current and electromotive force.

For the most part we have neglected this constant of integration because we have assumed that the disturbance or oscillations introduced in such a circuit very soon disappear. This, however, is not the fact where self-induction and capacity both are contained within such a circuit.

Even with self-induction and resistance only, or capacity and resistance only, theoretically the resultant current from such oscillations will never become zero. Practically, however, the resultant current in such circuits very soon becomes zero.

Referring to Mr. Campbell's paper, equation No. 1, and the last term of that equation, which is $C e^{ipt}$, it may be said that this term is of the nature of the constant of integration to which reference has been made above, but in order that we may adopt symbols to correspond with those used in the paper it should be remembered that C and p are constants either real or complex and that e is the Naperian base and i is the imaginary symbol corresponding to j as used by Steinmetz.

The term p is a constant, either real or complex, and represents the condition of the circuit or network as regards self-induction, capacity and mutual induction, and the other letters of the equation represent quantities as above explained.

Let us now turn to a few paragraphs of Mr. Campbell's paper in order to ascertain in a general way his method of treatment of the subject, the mathematical character of " cisoidal oscillations " and his extremely valuable and specific results and conclusions regarding such oscillations in circuits of the character of existing telephone distribution systems.

In the first place, the paper is not only mathematical but it is more than that; it is metaphysical in its treatment. The author has clearly pointed the way to the treatment of these peculiar oscillations and indicated a method whereby we may thoroughly understand the action, although we may not have control over the establishment, of such oscillations.

In a way his treatment of the subject is analogous to the mathematical treatment of alternating currents many years ago, in which it was shown that the laws of direct currents would not hold for the newly developed alternating currents. In this paper we have the mathematical treatment of these peculiar oscillations, which is a distinct addition to the mathematical treatment of alternating currents in somewhat the same manner as the mathematical treatment of alternating currents was a distinct step in advance of the equations which were satisfactory for direct currents.

To understand the character of these oscillations we need only consider a portion of the first paragraph of the paper, in which it is stated that these oscillations are sustained logarithmically, damped, or aperiodic, depending upon whether the time coefficient p, which really indicates the character of the circuit, is real, complex or purely imaginary. Further, the author has used the term " cisoidal oscillations " in order to emphasize the distinctive character of such oscillations and at the same time to indicate the close relation between such oscillations and the more generally known sinusoidal oscillations.

It is apparent, especially in telephone circuits, that while primarily we have to deal with oscillations which may be assumed equivalent to sinusoidal oscillations, yet in such circuits containing resistance, inductance and capacity it is quite as necessary to understand the laws governing this new kind of oscillation to which the author has given the name " cisoid."

We may get a somewhat clearer idea of these oscillations, as the author states that they are uniquely simple, because the ratio of the instantaneous electromotive force to the instantaneous current is not a function of the time.

Further we are told that the solution for cisoidal oscillations in any finite network may be written down directly without solving differential equations or the use of integration or differentiation.

The author brings out the fact that the use of vectors in the solution of complex quantities in alternating current theory is unfortunate and logically incorrect, and that the tendency of such use of vector quantities in ordinary alternating current theory tends to divert attention from the algebraic theory of complex quantities, which are of the greatest practical assistance in the mathematical treatment of cisoidal oscillations.

The mathematical treatment of the subject by Mr. Campbell in general is to use the mathematical process known as determinants, in order to obtain what he calls the discriminant A of a network, and in Table I, is to be found effective impedances or equivalent networks with two accessible circuits in terms of each other, and of the determinant A. As showing that these peculiar oscillations may be indefinitely sustained and that therefore they must be given consideration in telephone circuits, we find a statement to the effect that the activity of the external sources of power which produce *steady* cisoidal oscillations in any invariable network or one the constants of which remain invariable may assume a stationary value providing such value is consistent with the conditions necessary for current continuity and the conservation of energy.

The author has indicated in a most satisfactory manner the mathematical treatment for the conditions existing in an infinite number of circuits which correspond to our well-known eddy currents and to the skin effect, or the unequal distribution of current throughout a cylindrical conductor, which as we know involves conditions regarding which we must make allowances for certain quantities of current for frequencies above those nominally used.

In conclusion, and referring to the summary given in the paper, the author interprets his results from the mathematical standpoint, which concisely are:

1. The complex exponential function or mathematical expression of cisoidal oscillations is a mathematical term of fundamental importance in its own right and enjoys algebraic power or energy relations quite as important as those of real functions.
2. The correlation between sinusoidal and cisoidal oscillations may be reduced to a few simple rules covering power, currents and electromotive force.
3. The distribution of currents in any network of conductors having constant values is that of stationary dissipation of power.
4. The distribution of cisoidal currents in such a network is reduced to the equivalent condition of stationary driving point impedance or admittance.
5. The cisoidal power may be and is employed as a most convenient means for investigating the division of instantaneous power between resistances and reactances of a circuit or network.
6. Determinants may be used for the general solution of cisoidal oscillations in any invariable network or network having constant values, and the author has shown how the different impedances of such a network may be found directly and has also indicated how concealed circuits, mutual impedances or self-impedances may be eliminated. Also the author has given applications covering free oscillations and infinite systems of circuits.

In conclusion it should be said that not only is this paper of Mr. Campbell's fascinating from the standpoint of the application of mathematics to physical problems, but he has indicated a method of accurately determining the conditions existing in telephone circuits in which there are oscillations due to self-induction and capacity over which in practice we have practically no control, and if you can imagine conditions in a circuit in which the ratio of instantaneous electromotive force to instantaneous current is not a function of time we can to a small degree appreciate into what depths Mr. Campbell has extended his investigations leading to the solution of what are unquestionably some of the most important problems to be met in the transmission of telephonic currents in extensive telephone transmission systems.

A paper presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, April 26, 1911.

NEW AUTOMATIC TELEPHONE EQUIPMENT

BY CHARLES S. WINSTON

Automatic schemes for establishing connections between telephones were devised early in the history of the telephone movement and many of the first patents, which were issued for telephone inventions, were for devices which are the forefathers of the automatic equipment in use to-day.

During the first 25 years of telephony's history, a few automatic switchboards were installed, but it was not until the installation of the exchange at Grand Rapids, in 1903 that automatic apparatus received very serious consideration from the general public or from engineers, with the exception of a few who were, in most cases, personally interested in its advancement. During the last eight years interest in the automatic method has increased, many articles in regard to it have been written, and now a casual mention of the subject in almost any gathering of men in the telephone business is enough to cause heated discussion in regard to the relative advantages of manual and automatic. Recently new foes, near relatives, of automatic have appeared upon the horizon, which seem destined to play very important parts in the history of the telephony of the future—the automatic-distributing and semi-automatic systems.

In order to prevent misunderstanding, it may be well to state that throughout this paper a switchboard which requires automatic calling devices or dials at the subscribers' stations and no operators at the central office will be referred to as an automatic switchboard. An automatic-distributing switchboard will be one in which automatic switches are used for distributing calls to idle positions where operators establish connections by means of plugs and multiple jacks, as in the well known manual multiple switchboard, and a switchboard in which the connections between lines are made by means of automatic switches, which are operated by devices manipulated by operators, will be referred to as a semi-automatic switchboard.

The work of designing, perfecting and manufacturing an entirely new line of automatic equipment requires an immense amount of study and experiment. For sometime the company with which the writer is associated has been developing apparatus which will enable it to manufacture automatic equipment which will meet all of the requirements of automatic, automatic-distributing and semi-automatic. In this article a description will be given of parts of this apparatus which it is not expected to use in practice, but which may be of interest from an historical standpoint, as well as of apparatus which with certain changes will, in all probability, be put to practical use in the near future.

Different types of switches are not required for each of these branches of automatic, as the switches which are suited for one can, with slight modifications, be used equally well for the others.

Up to the present time, the " Strowger " switch is the only one which has been used to any extent. When used as a selector, the wipers of this switch, which are attached to the shaft, move vertically in response to current impulses caused by the operation of the subscriber's dial, and then rotate horizontally until idle trunk contacts are reached. The switches of the five following types will do the same work as that done by this switch, but in a radically different manner. For the lack of more satisfactory names, the switches will be referred to as:

1. Circular polywiper.
2. Circular long and short step with one driving magnet.
3. Circular long and short step with two driving magnets.
4. Double rotary with back release.
5. Double rotary with forward release.

1. CIRCULAR POLYWIPER SWITCH

Fig. 1 shows a plan view of the circular polywiper switch and a side elevation with certain parts in section. For all practical purposes it consists of two separate switches, each with a distinct driving magnet, wipers and bank contacts, which are built together in one structure to economize space and to facilitate wiring.

Instead of following the usual practice of attaching flexible cords to the wipers and thus continuing the circuit to the desired contacts of the bank, wires are carried to circular metal strips immediately below but insulated from the rows of individual contacts. The wipers serve to bridge together the individual contacts and these circular strips. In this manner all cord troubles are eliminated, although there are two movable contacts in each connection instead of one.

The bank consists of five circular rows of contacts, each row being divided into ten equal groups. There are two sets of wipers—the primary *P* and the secondary *S*. The former consists of ten separate single wipers which are mounted upon 36-deg. centers on the plate 1, which is rigidly secured to the shaft *P S*, while the secondary wipers consist of 10 sets of four wipers each, mounted similarly upon plate 2, which in turn is fastened to the shaft *S S*. The two shafts *P S* and *S S* are attached to ratchet wheels *P R* and *S R* respectively and through them the primary wipers are controlled by the magnet *P M* while magnet *S M* controls the secondary wipers.

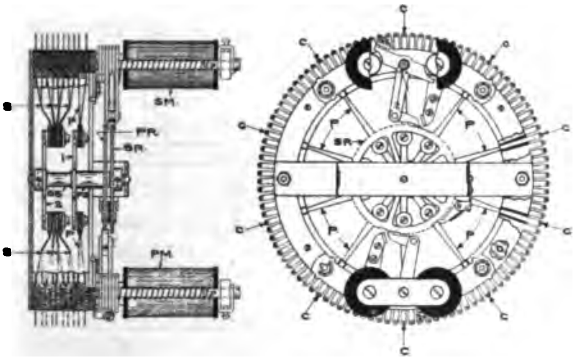

FIG. 1.—Circular polywiper switch

When in normal position, the primary wipers *P* rest upon contacts *C* and the secondary wipers *S* upon the contacts in line with and below contacts *C*, while these connections will be broken when the wipers are moved forward by the operation of the driving magnets. When the wipers have moved 11 steps the same condition will again be met and the switch will again be in normal position.

In Fig. 2 is shown the wiring of a first selector, individual to a line, using a switch of this type, with the wiring of a subscriber's telephone including a calling device. When the switch is normal the 10 primary wipers will be in the positions shown at *P*, while *S* represent the positions of the various secondary wipers. The common strips *M*, *N*, *O*, *M*1, *M*2, *M*3, etc., are each associated with 10 contacts instead of three as shown. The system illustrated uses a single source of current for both signalling and talking, while a ground return circuit is used for operating the relays which in turn operate the magnets which move the switch wipers.

In order to assist in giving an understanding of this switch, the method of operation of the circuit shown will be described briefly.

A subscriber desiring to converse with a second subscriber will remove his receiver from its hook, thus establishing a path for current through relays *P R* and *S R* and the apparatus in his instrument. He will then operate the calling device, thus connecting springs *A* and *B* to ground and breaking contact *c* a definite number of times, while current flowing from ground over line conductor *L*2 will maintain relay *S R* in the energized position. Each time the circuit is broken in this manner, relay *P R* will be de-energized and contact *E* closed, thus sending current through the primary magnet *P M*, and causing the primary wipers of the switch to make a certain number of steps. (Secondary contacts *K*1 and *K*2, *K*3 and *K*4, *K*5 and *K*6, *K*7

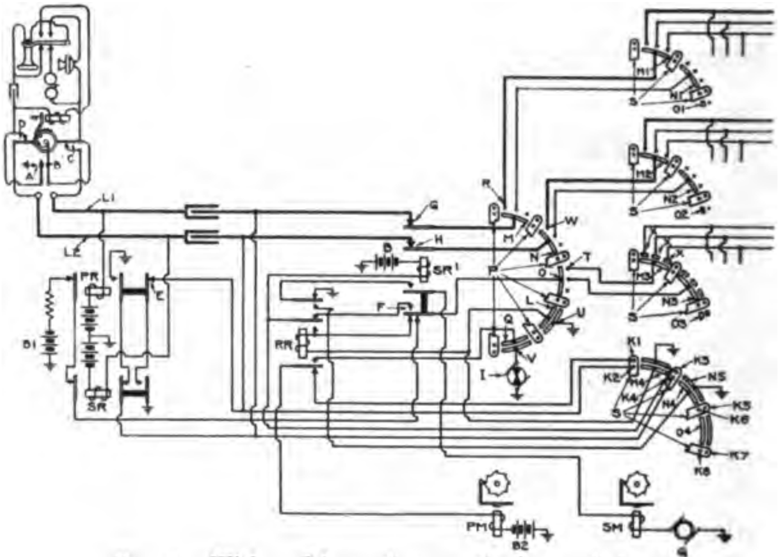

FIG. 2.—Wiring of first selector polywiper switch

and *K*8 are connected together through wipers whenever the switch is in the normal position.) Immediately thereafter and just before the calling dial returns to normal, both line wires remaining grounded, contact *D* will be broken once, thus holding relay *P R* energized and causing one de-energization of relay *S R*. For the purpose of illustration, suppose that the subscriber desires conversation with a second subscriber whose number begins with one. The primary magnet would then take one step, establishing connections between *M*, *N*, *O*, *L* and *Q*, and *R*, *W*, *T*, *U* and *V* respectively. Immediately thereafter, the de-energization of relay *S R* as above explained, will cause the energization of relay *S R'*. It will be noticed that the energization of the latter relay will establish a circuit from the negative pole of battery *B*, through the winding of this relay, back contact of relay *R R*, through the normally open contact *F* of relay *S R'* to the contact plate 0, through the wiper to contact *T*, and thence to common plate *M*3 of the secondary contacts. The energization of relay *S R'* will also close a path from the alternating-current generator *G* through the secondary magnet *S M*, thus moving forward the secondary set of wipers *S*. If the private contact *x* is busy, due to a ground on the corresponding contact of some other switch, relay *S R'* will remain energized and the switch wipers will be stepped ahead until a contact is found which is clear, when relay *S R'* will be de-energized and the switch will come to rest. The de-energization of relay *S R'* will close the talking circuit from the subscriber's instrument, through contacts *G* and *H*, and the primary wipers and concontacts, to the secondary wipers and thence to a second selector.

When the subscriber returns his receiver to its hook, relays *P R* and *S R* will be de-energized, thus causing relay *R R* to be energized by current flowing from ground at switch contact *U* to the negative pole of battery *B*1 and locking relay *R R* through *S R'* to battery *B*, thus cutting off the circuit from battery *B*1. The energization of the latter relay will again establish a circuit through the secondary magnet *S M* to ground at *N*5, while the energization of relay *R R* will cause current to flow from battery *B*2 through the winding of the primary magnet *P M*, a primary wiper and contact *V* to ground, through the interrupter *I*. The energization of these two magnets will be continued till the wipers have been driven ahead until they rest at *P* and *S* upon the normal contacts between the groups, at which time the circuits for all relays will be opened and all apparatus will be in normal position.

In the circuit shown, but five of the ten primary groups of contacts are used. It will, therefore, be seen that a large number of contacts are available for use as " off normal " contacts if the circuit requirements make it desirable. This feature of the switch is one of its chief advantages, but the difficulties which are necessarily met with in assembling and in wiring make it impracticable from the standpoint of manufacture and operation.

2. Circular Long and Short Step Switch with One Driving Magnet

As shown in Fig. 3, the construction of the long and short step single driving magnet switch is similar in general appearance to the polywiper switch, there being 10 circular groups of 10 contacts each. However, there is but a single set of wipers, which when moved forward by the driving magnet *M*, the magnet *M'* being de-energized, passes over one group of ten contacts at each step. If, however, magnet *M'* is energized at the time when the wipers are being stepped forward, the movement of armature *A* will be shortened by the stop *S* and the wipers will move from one set of contacts to the adjacent contacts for each energization of magnet *M*. As will be seen from this statement, each one of the 10 circular sets of contacts corresponds to a row of contacts on a vertical and rotary switch. That is, in this switch the wipers instead of moving a certain number of steps in one direction and then rotating at right angles, move a certain number of long steps and then take short steps

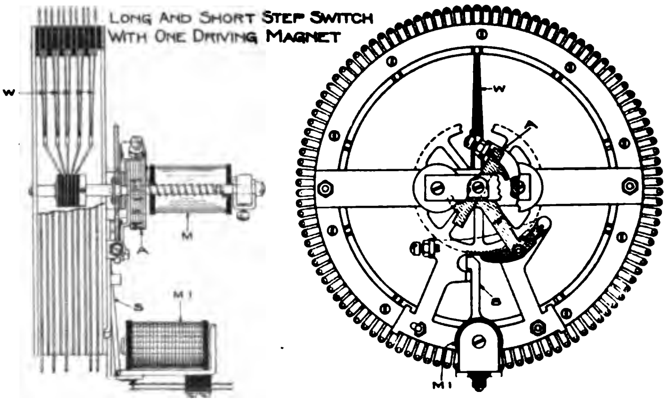

FIG. 3.—Long and short step switch with one driving magnet

until they arrive at contacts of a trunk line which is not in use, in the case of a selector, or until the contacts of the desired line are reached, in the case of a connector.

3. CIRCULAR LONG AND SHORT STEP SWITCH WITH TWO DRIVING MAGNETS

This switch is very similar to the one just described. The only difference of importance is that instead of using a magnet to limit the stroke and hence to move the wipers from one contact to the next, two separate magnets are employed, one for giving the long steps and one for giving the short.

4. DOUBLE ROTARY SWITCH WITH BACK RELEASE

It will be seen upon referring to Fig. 4, which shows this switch as a first selector, that the contacts are mounted in 10 separate strips or groups, each of which has 10 sets of contacts (each set consisting of two line contacts and one private contact) arranged in an arc of a circle, so that when completely assembled, all contacts point inwardly toward a common center,

Instead of using a single shaft, with the wipers rigidly attached. which moves vertically to select a group of contacts and then revolves horizontally to select the trunk, two shafts are used in this switch. One, to which the wiper frame is directly connected, rotates in a horizontal plane to select the group. The second is so connected to this frame that its downward movement gives the wipers a second rotary movement, thus stepping them upward into engagement with the bank contacts. Primary and secondary magnets are used for accomplishing these results, and the switch is returned to normal by means of a release magnet. Because of the relative arrangement of shafts and wipers, the latter move four or five times as great a distance as the former for each energization of either the primary or secondary driving magnet; and hence the movement of the armatures of these magnets is exceedingly small. It has been found from experiment that, due to this construction, switches of this type operate satisfactorily when the voltage of the storage battery used therewith is as low as 35 and that the height to which the voltage may rise does not affect the operation, as current of any voltage which the relays, used with the switch, can stand without injury may be employed. Hence, it is not necessary to use two sets of batteries—one for discharge while the other is being charged—or to resort to the use of extra storage cells or counter e.m.f. cells to maintain a constant voltage.

This switch is constructed so that the switch proper, consisting of relays, wipers and driving magnets, is supported by the frame of the contact bank in such a way that the switch can be removed instantly if trouble occurs without it being necessary to unsolder wires. The contact bank is fastened to the iron framework which supports all switches and hence the multiple wires do not support the bank when a switch is removed.

FIG. 4

FIG. 5

5. DOUBLE ROTARY SWITCH WITH FORWARD RELEASE

This switch, which is shown in Fig. 5 as a connector, is similar in many respects to the switch just described. The arrangement of the bank contacts is similar although more space is provided in this switch in order to facilitate the multiple wiring. Primary and secondary magnets give the wipers a double rotary motion but, in releasing, the magnet which has caused the vertical movement is again brought into use and the wipers are driven forward to the end of their vertical stroke. When this position is reached, a projection carried upon the wiper arm releases a retaining pawl, which has kept the wipers in the position into which they were driven by the primary magnet, thus allowing the wipers to move horizontally due to spring tension. When they have returned in this direction as far as possible, which is to a position directly above their normal position, a second retaining pawl, which after each vertical step has kept the shaft in its vertical position, will be released and the wipers will be returned to normal position.

As the release of this switch is accomplished by driving the wipers forward, clean contacts are at all times assured. In back release selector switches the last contacts in all rows are used infrequently, and hence they become coated with dirt and grease, thus preventing satisfactory connections when it becomes necessary to use them. Another advantage of this type of construction is that the wear on all contacts will be equal and hence the life of the bank increased.

During the last year a life test was made with a switch of this type. The switch was subjected to all the mechanical and circuit changes which it would undergo in practice in operating 1,378,000 times, which is equivalent to the use which an average switch in an exchange of 10,000 lines, would receive in 37 years' service. As, however, the wipers continuously passed over the tenth row of contacts, instead of each of the ten an equal number of times, the wear on these contacts was equal to what it would be in 370 years of service.

AUTOMATIC CALLING DEVICES

Second only in importance to the selector and connector switches, if it is not of equal or even greater importance, is the calling device used at the subscriber's station. The design of a calling device which will meet all conditions of service is an extremely difficult problem. The work to be done requires complicated mechanism which, as it is to be used by unskilled hands, must be strong, positive in operation and "fool-proof." If a switch fails to properly perform its functions an attendant who is always present can remedy the trouble, but trouble in a calling device makes necessary a trip of the troubleman at an expense which may not be small.

It is possible to design calling devices of a great many different types, and numerous patents have been issued for schemes of various kinds. In connection with the automatic development referred to, calling devices of six or seven different types have been made. Some are of the " finger-hole " type, others employ a lever for their operation, while one has been developed in which the subscriber sets up the number of the desired station on the face of the device before sending the impulse. A cut of this device is shown in Fig. 6. Upon referring to this figure it will be seen that there are in the top plate five circular openings through which digits are visible. Extending from the side of the device below these openings are five buttons which when turned either to the right or to the left change the figures from 1 to 0. Therefore, it is possible to set up any number between 00000 and 99999, or in other words to use this device as shown, in a one-hundred thousand line system.

The method of procedure in making a call with this device is as follows: The subscriber removes the receiver from its hook, turns the buttons in the calling device (this can also be done before removing the receiver if desired) until the proper number appears, and turns the lever at the right hand end until a stop is reached. The mechanism within the device will then operate and cause the operation in succession of the selector and connector switches. During the time that the impulses are being sent, the figure-changing buttons, as well as the sending lever, will be locked so that the subscriber cannot interfere with the signalling.

FIG. 6

The advantages of an instrument of this type are obvious. With calling devices of the usual type, a very large percentage of the errors made in calling are due to mistakes of the subscribers, and not to the apparatus, but such errors cause complaint and dissatisfaction and often the loss of subscribers. A calling device of this type will eliminate such errors entirely. The objection has been made to any device in which the number is set up, that if a wrong station is called and the subscriber sees that the proper number is before him, he will know that the fault is in the equipment, and the eloquence of the troubleman cannot change his view. This is seemingly very weak argument as automatic apparatus which must rely upon such subterfuges to retain the good will of the users is not what it should be.

One of the calling devices, of the finger-hole type, which has been developed possesses several novel features. In operating, the finger is placed in the hole associated with the proper number and the front plate rotated until a stop is reached. When the finger is withdrawn the front plate rotates backward, under the control of a very simple governor, breaking a contact a definite number of times. The mechanism is not locked at any time and the subscriber must use care to complete the movement of the dial and not to retard the front plate during its backward stroke. If either of these precautions is disregarded the call will not be made properly. This dial is very simple and inexpensive and the cost of maintenance would unquestionably be very low. It is, however, extremely doubtful whether, in the present state of automatic, the general public can be relied upon to use the precautions necessary for the satisfactory operation of so simple a dial, but if automatic exchanges increase in number it will not be surprising to see a simple dial of this sort used, as soon as telephone users are sufficiently educated.

CONNECTING CALLING LINE TO SWITCHES

Various methods have been employed in automatic systems for connecting the subscribers' lines to the first selectors. The old Strowger plan, which is used in a large number of automatic installations, provides an individual first selector for each line, and it is very doubtful whether any of the other schemes which have been used up to this time are its equal when the cost of maintenance is considered as well as initial cost. Several years ago engineers saw that an individual first selector was more expensive than necessary and various substitutes have been devised. The scheme which up to this time has been most extensively used, is the so-called " Keith Unit " which has been described so frequently that description here would be superfluous.

Another scheme which has been proposed is the " back-selecting " scheme. Two relays, a line and a cut-off, are furnished for each line, and when a call is initiated, the energization of the line relay sets in motion the wipers of a line-finding switch, which travel over bank contacts until they come to contacts which are attached to the calling line, where they stop and thus connect the calling instrument to a first selector.

Another plan which has not yet been used in practice but which has many advantages is to use a small 10- or 15-point line switch for each line. In addition to the switch mechanism, which includes one driving magnet, two or possibly three relays per line are required in order to bring about the necessary circuit changes. With this scheme, when a subscriber removes his telephone from the hook, a line relay will be energized and current will be sent through the driving magnet, which will step forward the switch wipers. When contacts which are attached to an idle first selector are reached, the movement of the wipers will cease and the circuit will be continued from the subscriber's instrument to the selector. As one switch is required for each line, it is possible that, although it is comparatively inexpensive, the cost will be greater than that of either of the two other schemes mentioned, but a slight additional cost is seemingly justifiable in order to make it impossible for trouble in a switch to throw out of service more than one line. With the individual line switch, trouble in the line switch may prevent the associated line from calling, but it can have no effect upon a second line. The circuit of a switch of this type will be shown later in connection with the description of the circuits of a complete two-wire system.

AUTOMATIC SWITCHBOARD

The automatic switchboards installed previous to the last few years used local battery in each instrument for furnishing talking current while the signalling was accomplished by means of current from a storage battery located at the central office. These systems were "three-wire" systems in which the signalling current returned from the subscriber's station through the earth. As electric car lines and electric lighting plants increased in number, it was found that, as in other branches of telephony, earth potentials caused trouble, thus making it necessary, in extreme cases, to substitute for the earth return an additional wire for each line or a common return wire, which served a number of lines.

The first common battery automatic installations were also three-wire systems, but the trouble due to signalling through ground was so great that it was necessary for engineers to devise means which would enable the signalling to be done over a metallic circuit. A number of plans were proposed, one of which was the use of the "slow-acting" relay. That is, a relay which, when energized by current, will hold its contacts closed for a short period after the circuit through its winding has been broken. The means generally used for accomplishing this result is either to place a copper sleeve over the core of the relay or a large amount of copper over one end of the core. A relay built in either of these two ways answers the purpose admirably and by increasing or decreasing the air space between the armature and the pole piece, varying degrees of sluggishness can be obtained.

The circuits of a two-wire system including a subscriber's instrument with a calling device of the " set-up " type, an individual 10-point line switch, first selector, second selector and connector, using the double rotary switch with forward release, are shown in Figs. 7 to 10. It should be borne in mind that it is improbable for various reasons that the circuits shown or the apparatus will be used in practice without changes of a more or less radical nature.

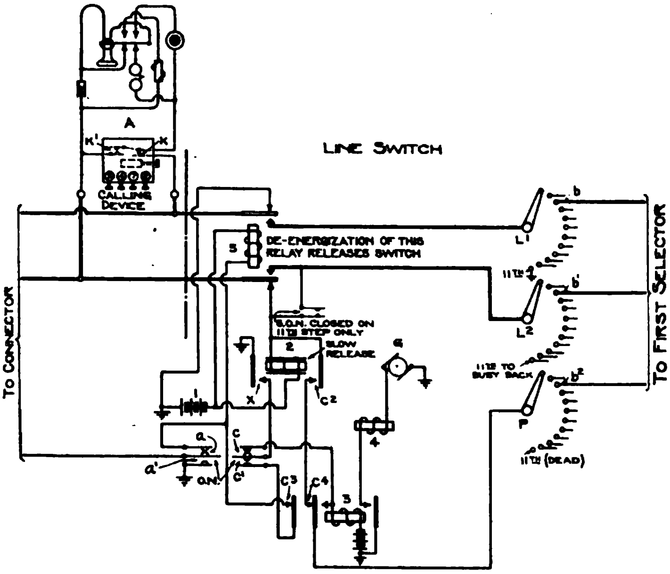

FIG. 7.—Line switch

The various steps which take place in establishing a connection between two stations as *A* in Fig. 7 and *B* in Fig. 10 will be as follows:

When the subscriber at station *A* removes his receiver from the hook, he will establish a circuit from the grounded terminal of battery 1 over the metallic circuit of the telephone line, through the winding of relay 2 to the negative side of battery 1. Current flowing in this path will cause the energization of this relay, thus establishing a second circuit through the winding of relay 3.

The energization of the latter will allow alternating current from generator *G* to pass through the winding of driving magnet 4, thus stepping forward the wipers of the switch, so as to engage contacts of the switch bank. The connections of the off-normal springs *O N* will be changed as soon as the wipers have taken the first step from their normal position, and hence contacts *c* and *a* will be broken and *c'* and *a'* closed. It will be seen that as soon as these changes take place the circuit over which relay 3 was energized will be broken at contact *c*, and hence that this relay will then depend for its continued energization upon the condition of the contacts over which the private wiper *P* is passing. The bank contacts of this switch are multiplied with the bank contacts of other line switches and are connected to first selectors. When a first selector switch is in use, its private contact will be connected to ground as will be described later. If then, the first private contact is grounded when wiper *P* reaches it, relay 3 will remain energized and the driving magnet will step the wipers ahead until a second contact is reached. If this contact is not connected to ground, relay 3 will fall back to normal, thus breaking the circuit through the driving magnet 4 and the wipers *L'*, L^2 and *P* will come to rest upon contacts *b*, *b'* and b^2 respectively. When relay 3 becomes de-energized, a circuit will be closed through contact *x* of relay 2, closed contact *c'* of the off-normal springs, back contact c^3 of relay 3, and the winding of relay 5. Current flowing through the winding of relay 5 will cause it to attract its armature, thus opening the circuit which previously existed through the winding of relay 2.

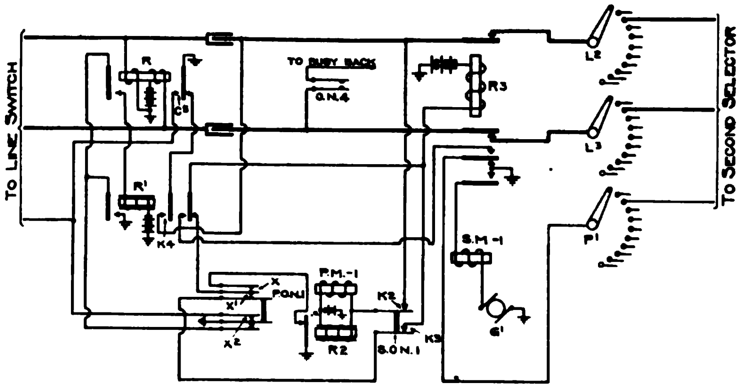

FIG. 8.—First selector

This latter relay would fall back immediately were it not for the fact that it is a slow releasing relay. The instant that relay 5 is energized, relay R of the first selector (Fig. 8) will attract its armature, due to current flowing through its two windings and the subscriber's line and instrument in series, thus causing the energization of relay R' and connecting ground through contact c^5 to contact b^2 on the line switch, and preventing other line switches from connecting with this first selector. The energization of relays 5 and R is accomplished in a small fraction of a second and relay 2, although the original circuit through its winding was opened by relay 5, remains energized over a second circuit which extends from battery 1 through its winding, contacts c^2 and c^4 private wiper P, bank contact b^2 to ground at the armature of relay R.

The calling instrument will then be connected to a first selector, and the subscriber will proceed to set up on his calling device the number of the station desired, for example 5472, and turn the starting lever. Contact K will then be opened and closed five times while contact K' remains closed, thus preventing the subscriber from receiving a disagreeable click. Each time the circuit is broken and closed in this manner, relay R of the first selector will be de-energized and energized and a circuit will be established five times momentarily from ground at the armature of relay R, through contact K^4 of relay R' contact K^2 of the secondary off-normal, thence through relay R^2 and the horizontal or "primary" magnet, $P\,M - 1$, in multiple to the negative or non-grounded side of battery. The relay R^2 will attract its armature the instant current flows through its winding, and as it is of the slow-release type, its contacts will remain open during the make and break periods of relay R, and the primary magnet $P\,M - 1$ will force the wipers of the switch forward one step, in the horizontal direction, for each current impulse. After the impulses cease relay R^2 will fall back and current will flow from ground through the contact of relay R^2 and the primary off-normal contacts x and x', (the three springs which form these contacts will be bunched at all times when the switch is out of its normal position) through the secondary off-normal K^3 to the negative side of battery through the winding of relay R^3. The energization of this latter relay will close a path for alternating current from generator G' through the winding of the vertical or "secondary" magnet $S\,M - 1$ to ground, thus causing the switch wipers to move vertically and hence to engage the bank contacts. As soon as the switch makes one vertical step, off-normal contacts K^2 and K^3 will open and relay R^8 will depend for its continued energization upon the condition of the contacts over which private wiper P^1 is passing. As soon as this wiper rests upon a contact which is not busy and hence ungrounded, the flow of current through the relay R^8 will cease, thus breaking the circuit through the secondary magnet, and the switch will come to rest. The circuit from the subscriber's instrument will then be continued to a second selector. The falling back of relay R^8 will place a ground upon wiper P', thus rendering the second selector busy and preventing other first selectors from being connected with it. This ground connection will also cause the energization of relay R^4 of the second selector.

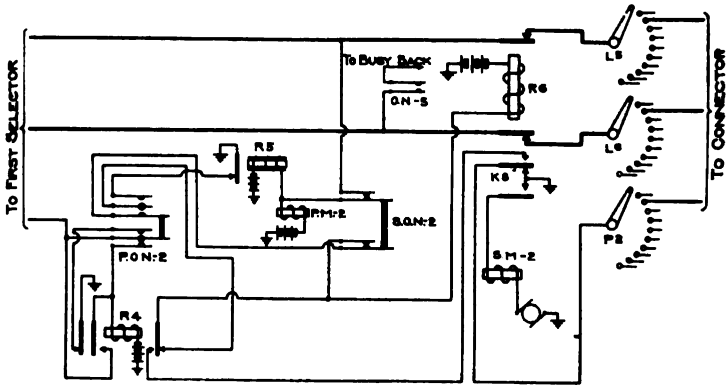

Fig. 9.—Second selector

After these circuit changes have taken place, the subscriber's calling device will break and close the line circuit four times, and again relay R of the first selector will be de-energized and energized. At this time, however, the circuit through the primary magnet $P\,M - 1$ of the first selector will be open at the secondary off-normal contact K^2, and circuit changes similar to those which took place at the first selector will occur at the second selector (Fig. 9). When relay R^6 of the second selector falls back after an idle contact has been located by the private wiper P^2 the calling line will be connected through the line wipers L^5 and L^6 to the connector, and a ground connection will be placed upon the private wiper P^2 which will render the selected connector busy and establish a circuit through which relay R^7 of the connector will be energized.

When the calling device causes the de-energization and energization of relay R of the first selector for the third time, the primary magnet $P\ M-3$ of the connector (Fig. 10) will move the wiper seven steps in a horizontal direction, while the slow-acting relay R^8 will retain its armature in the attracted position. When the impulses cease and relay R^8 is restored to normal, relay R^9 will be energized over the path which begins at ground at the primary off-normal contact $P\ O\ N-3$ and extends through contacts K^5 and K^6, the winding of relay R^9 to battery. As soon as relay R^9 is energized, contact K^7 will be closed and K^6 broken and hence this relay will depend for its subsequent energization upon current flowing from ground through contact K^8 of relay R^6 of the second selector. The energization of relay R^9 will cut the primary driving magnet out of circuit and in its stead place the secondary magnet $S\ M-3$. This is the condition of affairs which will exist when the last set of impulses, two in number, is sent from the calling subscriber's station. The secondary magnet $S\ M-3$ will give the switch wipers their vertical movement while relay R^8 will be energized a second time and locked, while the impulses are being sent, through its own contact K^{12} (contact K^{19} of the secondary off-normal opens with the first vertical step of the wipers) and assume its normal position as soon as the flow of interrupted current ceases.

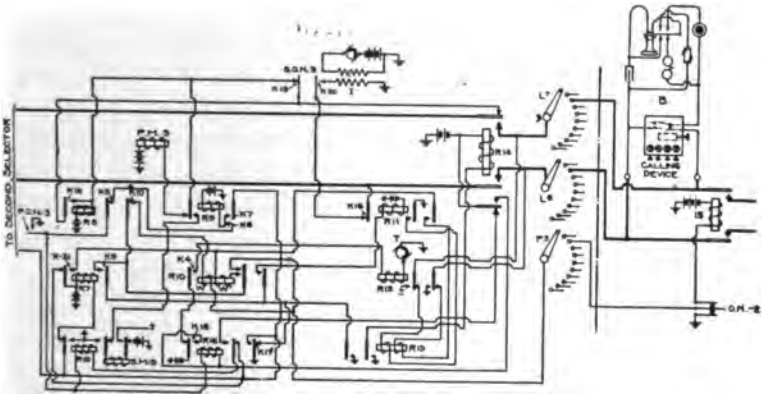

FIG. 10.—Connector

At this stage of the proceedings one or two things will happen, depending upon whether the called line is busy or not busy. If busy, the private contact upon which wiper P^3 rests will be connected to ground at the off-normal contact $O\,N - 2$ or at a second connector which is connected to the called line. As a result relay R^{10} will remain inactive and the busy-back signal will be given to the calling subscriber. The circuit over which this signal is given may be traced from ground at the busy-back induction coil I, through contact K^{20} of the secondary off-normal $S\ O\ N - 3$ contact K^{16} of relay R^{11}, to one side of the talking circuit, thence to ground through one winding of relay R and also over the subscriber's line and through the second winding of relay R. If, on the other hand, the line is not busy when the wiper P^3 reaches its private contact, current will flow from the positive pole of battery at contact K^{17} of relay R^{16} through contact K^9 of relay R^7, contact K^{10} of relay R^8, winding W of relay R^{10} to the private wiper P^3, thence to the private contact of the called line, through the winding of relay 15 to the negative pole of battery. Current flowing over this path will energize relays R^{10} and 15. A circuit which maintains relay R^{10} energized will then be established, through the winding W^1 and contacts K^9 and K^{21}, which will shunt out of circuit winding W and also connect ground to private wiper P^3 thus rendering the called line busy. Relay R^{11} will be energized immediately after R^{10}. When contact K^4 of the latter is closed current will pass intermittently through the winding of relay R^{12} and the interrupter T in series, thus causing the contacts of relay R^{12} to be closed and opened alternately, and connecting ringing current through the wipers L^7 and L^8 to the called line. Each time relay R^{12} is de-energized, the two windings of relay R^{13} will be connected to the line, so that current will pass through them when the circuit is closed by the removal of the called subscriber's receiver.

When, in response to the ringing of the bell, the subscriber answers, relay R^{13} and hence R^{14} and R^{16} will be energized, and the instruments of the calling and called subscribers will then be connected together for conversation. Talking current for the latter will be supplied through the winding sof relay R^{13} while the calling subscriber will receive his supply of current from relay R of the first selector.

When conversation has been finished and the called subscriber hangs up his receiver, he will cause the connector switch to be released and restored to normal, while this same act on the part of the calling subscriber will restore the line switch, the first selector and the second selector. The control of these three switches rests primarily with relay R^1 of the first selector. When relay R is restored to normal R^1 will also be de-energized, and current will flow through the winding of relay R^3, causing the latter to attract its armature, thus closing a circuit for generator current through the secondary magnet $S\,M-1$. The latter will then drive forward the wipers of the switch and when the contacts of off-normal $P\,O\,N-1$ are opened, the circuit which has previously existed through R^3 will be opened and the first selector will be in normal position.

When the off-normal contacts $P\,O\,N-1$ resume their normal positions contact x^2 of the first selector will be opened and therefore relay 2, and hence relay 5 will return to normal position. The de-energization of the latter will restore the line switch wipers to normal.

When relay R^3 became energized, the circuit from ground over the private P^1 was broken and relay R^4 of the second selector assumed its normal position, thus causing the release of the second selector in a manner very similar to that in which the first selector was restored.

The method by which the disconnection of the connector is accomplished may be briefly described as follows: Relay R^{13} will resume its normal position the instant the circuit is opened at the called subscriber's switchhook. The cut-off relay R^{14} will then be de-energized but relay R^{16} which was energized when the called station responded, will remain in its energized position due to current flowing from ground at off-normal $P\,O\,N-3$ through its winding and normally open contact K^{13} to battery. Therefore, upon the de-energization of relay R^{14}, relay R^{15} will attract its armature, thus allowing alternating current to flow through the secondary magnet $S\,M-3$ and also placing ground upon the private contact and preventing the connector from being selected during the time of release. As soon as the primary off-normal contact is restored to normal, relay R^{15} will fall back and open the circuit through the secondary magnet. The switch and all relays have then assumed their normal position. If the called subscriber does not respond the control of relay R^{15} and hence the release of the connector switch will remain with the calling subscriber.

If, at the time a subscriber removes his receiver from its hook, each one of the 10 first selectors connected to the line switch is busy, the wipers of the switch will stop upon the eleventh contacts. As the eleventh private contact is dead, relay 3 will fall back and relay 5 will be energized as it will when the wiper P rests upon a contact of an idle trunk. However, there is provided on this switch a special off-normal contact *S O N* which is closed only when the wipers are in the eleventh position. In this case, therefore, as soon as relay 5 becomes energized, a path for current through relay 2 is again established over the subscriber's line, through the wiper L^1 to ground at the eleventh contact. A connection from the busy-back induction coil is brought to the contact upon which wiper L^2 rests and hence the subscriber will be notified that he cannot immediately obtain a connection. As soon as he hangs up his receiver, relay 2 and hence relay 5 will be de-energized and the switch will be restored to normal.

The first and second selector switches are each provided with off-normal contacts ($O\,N-4$ and $O\,N-5$ respectively) which will cause the busy-back signal to be given to a calling subscriber when the wipers of a switch have made eleven vertical steps, as will be the case when all of the ten trunks in a group are in use.

In nearly, if not in all existing automatic exchanges, battery current is used for driving the selector wipers to select an idle trunk. In some cases a break contact on the driving magnet interrupts the current, and in others an individual interrupter, which serves a number of switches, is used. As already stated, the system described contemplates the use of alternating current. It is the intention to use current of approximately 20 cycles and as a result the wipers will pass over the trunk contacts at the rate of 40 contacts per second. Therefore, in the case of the line switch one-quarter of a second will be required for the wipers to pass over an entire bank of ten contacts, and this speed is so great that there is no danger that the subscriber will operate his calling device before the trunk has been selected.

AUTOMATIC-DISTRIBUTING SWITCHBOARD

As no automatic-distributing system has been placed in operation, it is interesting only for its future possibilities. A multiple switchboard which is similar in appearance to a manual multiple switchboard will be used. No answering jacks or answering lamps are necessary and upon the key and plug shelves single plugs will appear instead of pairs of plugs. Switches, which may be of the same general construction as selector switches used in automatic switchboards, are required and at each subscriber's station will be a common battery telephone of the ordinary type, no calling device or additional apparatus being necessary.

In making a call the subscriber will remove his receiver in the regular manner, and by so doing will light a lamp associated with one of the plugs upon the keyshelf at the operator's position. It will be understood that switches similar to any one of the five selector switches already described and either an individual line switch or a back-selecting arrangement can be employed to continue the subscriber's line to the switchboard. The operation of a line relay in the back-selecting scheme will set in motion two separate switches, one will connect its wipers to the terminals of the calling line, while the second will select an idle cord at the first idle operator's position. When both of the switches have come to rest, current flowing through a relay over the subscriber's line will cause the illumination of a lamp on the keyboard in front of an operator. The operator will throw the listening key associated with this lamp and ascertain from the subscriber the number of the station desired. Having received this information, she will, without testing, insert the plug into the multiple jack of the desired line, extinguishing the calling lamp and lighting in its place a second lamp which acts as a supervisory. If the line is not busy, the bell will then be rung automatically until the subscriber responds, when the supervisory lamp will be extinguished. If the line is busy when the connection is established, the subscriber will receive the busy signal and upon hanging up will give the disconnect signal to the operator.

At the end of conversation when the two subscribers have placed their receivers upon their hooks, the supervisory lamps will light and the operator will withdraw the plug from the multiple jacks, thus restoring the switches as well as all other apparatus to normal position.

With this scheme a subscriber's line is not associated with one particular line lamp, as in the case of manual switchboards, but any subscriber may light any calling lamp in front of any operator's position. When a call is made, if no cords are in use, the first idle lamp in the first operator's position will be lighted, while a second call will come in upon the lamp of the next cord in the same position, and so on until all cords at the first position are in use. Additional calls will then automatically pass to the second position. In this way one operator can handle all calls at certain times of the day and when business increases a second operator can take up her duties, then the third and as many as may be necessary. It is not necessary at the time of light load for an operator to change from one position to another or to answer calls in multiple jacks as the automatic apparatus provided makes it unnecessary. It can readily be seen from the facts just stated that inasmuch as the operators work more efficiently than at a manual multiple switchboard, each operator can handle a greater number of calls, thus reducing the total number of operators required, and as a result the total number of switchboard sections. These are the advantages claimed for this system. If it is to be a success, the advantages must be great enough to outweigh the disadvantages due to the use of automatic switches, as well as to the initial cost of the equipment which is considerably more than that of a manual switchboard.

SEMI-AUTOMATIC SWITCHBOARD

Operators are also required in a semi-automatic switchboard but instead of using multiple jack equipment as in the automatic distributing, each operator is provided with a desk and apparatus which enables her to receive calls from subscribers, to operate selector and connector switches and thus establish connections between lines. Either individual line switches or a back-selecting scheme can be used to connect calling lines to the trunk circuits. The method of operation, using the back-selecting scheme, is as follows:

When a receiver is removed from its hook, the operation of the corresponding line relay sets in motion a line selecting switch which selects the calling line, and a second switch which selects the first idle trunk terminating at the position of the first operator having an idle trunk, thus connecting the calling line through these two switching circuits, and lighting a lamp in front of that operator. The operator's desk is equipped with two or more trunk circuits, each requiring a listening key and two, three, four, or five rows of ten keys each for operating the switches—the number of rows depending upon the size of the exchange. That is, if an exchange has an ultimate of 1000 lines, three rows will be required, while four are necessary for a 10,000 line system and five for a 100,000 line system. When the lamp associated with a group of keys lights, showing that a connection is desired, the operator will, by means of the listening key, place her telephone set in connection with the calling line. After ascertaining from the subscriber the number of the line desired, she will operate the proper key in each of the groups, thus setting up the number of the called line. Immediately after the key corresponding to the first digit is operated, current passing through an interrupter, which is individual to the trunk circuit, will operate the first selector associated with the line selector, and immediately thereafter a second impulse through the key corresponding to the second digit will operate the second selector, and in the case of 10,000 line system, a third and fourth impulse will complete the connection through the connector to the called line. As soon as the last impulse has been sent to the connector, the lamp on the operator's keyboard will be extinguished and the trunk over which the preliminary connection to the operator's desk was made, will be disconnected and placed in condition to receive a second call. The bell of the called station will be rung automatically and at the end of conversation the switches will be disconnected, without the assistance of the operator, when the subscribers hang up their receivers.

It is easily seen that many variations in the method of operation of semi-automatic can be made and that there is a wide field for argument as to the importance of certain features. It will be noted, for example, that in the operation described, the operator is disconnected from the subscriber as soon as the last impulse has been transmitted to the connector. Hence, if the attention of the operator is again desired by the subscriber, for any reason, the operation of the switchhook may place him in communication with a second operator, thus causing possible confusion and dissatisfaction.

It is probable that before many years the differences of opinion which now exist as to the relative advantages of manual and automatic will disappear, and that definite standards will be adopted for the various conditions of practice. It is possible that for localities of a certain size one system will be used while for larger and smaller installations entirely different systems will be found to meet the requirements more satisfactorily. It is now impossible to foretell what this ultimate solution of the problem will be, and one who is bold enough to attempt to do so is putting his reputation as a prophet to a severe test.

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THE SEMI-AUTOMATIC METHOD OF HANDLING TELEPHONE TRAFFIC

BY EDWARD E. CLEMENT

It is the purpose of this paper to describe briefly the Clement automanual telephone exchange system, explain its principles, and show some of the results it has produced. For proper presentation, and in order to make necessary comparisons, the subject will be developed as follows:

1. The limitations and waste necessarily involved in manually operated exchange systems.
2. Characteristic features and limitations of automatic methods.
3. The principles involved in the automanual system, and the manner in which they are applied to avoid waste, and secure increased economy and efficiency.

MANUAL SYSTEM

Some years ago it was generally agreed among telephone engineers that the limit of concentration had been reached in the 10,000-line multiple switchboard. It is true that switchboards of a much greater capacity than this had been designed and some of them built, but other reasons beside the mechanical and physical limitations of the central office equipment forbid extreme concentration. Among these the most important factor is that of the increasing ratio of non-earning investment in the cable and wire plant. It is unnecessary for me to recapitulate the figures that have been presented from time to time before the Institute, in support of this statement. It has been shown, and I believe is not disputed, that over 90 per cent, and in some cases 98 per cent of the wires are idle, on the average, during the

24 hours; and in well-designed systems observation has shown that the total number of connections established or in course of establishment simultaneously at the peak of the load is not more than 40 per cent of the number of sets of connective apparatus necessarily provided. This percentage of course does not refer to line terminals, of which the percentage is only a fraction of this. Since the wire and cable plant represents a large proportion of the entire investment in any existing system, either manual or automatic, it will be seen that important as the switchboard limitations are, their effect in determining the engineering policy is only contributory.

In subdividing the manual switchboard system to reduce cost, another element of expense is introduced which tends largely to offset the advantages of the subdivision. I refer to the necessity for trunking with all of its attendant problems, including the provision of extra trunk operators and the difficulty of maintaining the standard of efficiency as high as it would be in a single switchboard exchange. The maximum efficiency possible with strictly manual equipment is reached in the single switchboard exchange serving less than 10,000 lines and probably not to exceed 8,500. (This contemplates of course the use of substantial plugs and jacks, which are impossible in larger switchboards).

For purpose of comparison, and bearing in mind the established standard of efficiency, it may be well to note here the necessary steps in manually effecting a connection of two lines. Assuming modern equipment with so-called automatic ringing and centralized battery, the subscriber calls by taking down his receiver from the switch-hook, which automatically lights the line lamp. The operator notes the signal, picks up the answering plug and inserts it in the jack corresponding to the lamp; then throws over her listening key and inquires the number; picks up the calling plug and advances it selectively to the multiple jack of the wanted line; touches the plug tip to the jack thimble for test and notes the result; if line is idle inserts the plug; closes the listening key; presses down the ringing button; observes whether the called party answers; supervises the connection; finally removes the plugs and restores them to their seats. Should the line wanted test busy, the calling plug is not inserted, and the operator either advises the calling subscriber of the fact, or connects the busy-back signal. For party-line ringing an additional act is the selection of the ringing button.

This statement covers the duties of a subscribers' operator on a board having no trunking. The use of trunks introduces not only complication, but uncertainty and delay. In most manual systems the subscribers' or *A* operators communicate with the *B* operators over order wires, which requires the *B* operators after receiving the numbers to answer back and designate the trunks to be used in the connections. Uncertainty results, because the chances for error are obviously multiplied, and delays result which are equally obvious, since each trunk connection must go through two operators. Both the delays and the uncertainties affect the efficiency of the equipment and lower its earning power, as well as the efficiency of the service. Observation has shown that a very large percentage, rising as high as between 80 and 90, of all irregularities reported is due primarily to the trunking system. As an example of cost, in the West Exchange of the Kansas City Home Telephone System, the cost of handling trunked calls, amounting to 25 per cent of the total traffic, is over 31 per cent of the entire operating expense chargeable to that particular exchange. As the Kansas City Company has an economical schedule in vogue, this percentage is fairly illustrative of the condition in general.

The limit of subdivision in the manual system is reached when the saving in interest charges on the investment in the centralized cable and wire plant is balanced by the losses due to the increase in operating expense and the lowering of efficiency of operation due to trunking. To make this clear, it should be understood that in providing for traffic between switching centers or exchanges, the number of trunk pairs required bears no definite or fixed relation to the number of lines, but varies with several factors which must be determined for every plant. Assuming a minimum average number of trunks, bearing the same percentage relation to the total number of lines that the total load or number of simultaneous connections would bear at the peak, there would of course be a very large saving in first investment, but it would have to be effected by a perfect subdivision of the system into districts or sub-centers which would bear a fixed and invariable average relation to each other. Perfect subdivision of this kind is only theoretically possible, and it can very readily be shown that a saving by subdivision of say 30 or 40 per cent, in a large exchange carrying a heavy traffic load, in most cases would be offset by the increase in operating expense. For example, reference may be made o conditions in New York, where the trunking runs to over 90 per cent in certain exchanges. In Detroit, the average trunking percentage for all the exchanges was recently figured over 55. A subscribers' or *A* operator in these exchanges cannot average over 185 calls per hour, while the *B* operators would average about 350 in the busy hour and the general average for 24 hours would be under 180 per *A* operator-hour. The effect of the high percentage of trunked calls is apparent when this is compared with the operators' averages in exchanges where the trunking percentage is zero. In such an exchange an *A* operator working under the method I have outlined can handle between 280 and 290 calls in the busy hour and the average for 24 hours would be about 175 per operator-hour. This will be referred to again, in connection with the diagrams and tables.

Next to the limitation imposed by the necessities of trunking, the arbitrary arrangement and grouping of subscribers' lines on the *A* positions must be considered. The switchboard is divided into sections to which all the lines are multipled with three operators' positions per section arranged so that any one of the operators can reach a multiple or calling jack of any line entering the exchange. For answering purposes each position is equipped with a certain number of answering jacks with their accompanying signal lamps. The distribution of the lines among these answering jacks is arbitrary, and determined empirically by the requirements of the service. Inasmuch as no fixed and invariable rule can be laid down covering the percentage of calls originating in a given time in any one group of lines, obviously the number of answering jacks, or the number of lines to be handled by each operator, must be limited approximately by average or normal traffic conditions in the busy hour. In the Louisville Home Exchange, for example, where the average is 18.2 calls per line per day, the average number of lines per operator is about 105, and these are all individual lines, no party-line service being given. In the Bell Exchange at Detroit, where the load is very heavy, the calls averaging over 22 per line per day, the number of lines per operator is about 90. The development of party-lines is about 60 per cent. The Louisville exchange serves 10,000 subscribers, with six per cent trunking, and an average of 182,000 originating calls per day of 24 hours. Assuming that there would be 16,500 calls during the busy hour, if perfect distribution among the operators could be obtained, without otherwise changing the character of the switchboard, a maximum number of 57 operators only would be required in the busy hour instead of 63 or a saving of about 10 per cent.

A number of schemes have been suggested for securing this or a greater saving, all depending on the same fundamental principle of automatic intermediate distribution, by the use of a traffic distributor. That none of these schemes have gone into general use is at least a persuasive argument that this sort of distribution is recognized as a mere makeshift, and of itself is not attractive in view of the expense of its installation and the retention of the other objectionable features of the manual board.

In considering the figures given for this distribution, and its effect on the number of operators, it should of course be borne in mind that below a certain point on the load curve there is a loss of efficiency in any system, reached when the total load falls below the capacity of one or two operators to handle. This loss would be minimized however by the concentration of all calls at one part of the board when the load is very light, the effect being to save patrolling, which must be practiced at present, since calls may come in on any position.

The limitations of the manual board may be briefly summarized as follows: (1) the necessity for each act required in establishing and taking down a connection to be performed by the operator " by hand "; (2) the arbitrary and empirical grouping of lines on answering positions; (3) the small number of lines (relatively to the size of any well-settled district to be served) which can be concentrated at one operating center and handled by one group of operators, due to the mechanical limitation of space for multiples, and the cost of the cable and wire plant; (4) the great loss in efficiency, increase in operating expense, and depreciation of the investment in the multiple portion of the switchboard, as the percentage of trunked calls rises.

The existence of these limitations is generally recognized by companies operating manual boards, but not their extent. Traffic men know that at the very peak of the load in any exchange the number of plugs and cords in simultaneous use rarely exceeds 33⅓ per cent of the total number provided, which means an over-provision of 200 per cent of connective apparatus, with its attendant keys, signals, relays, etc., necessitated by the fact that one group of lines may be very busy while another group is comparatively idle. Some companies, where the trunking percentage exceeds 85, omit the multiples entirely from their *A* boards. The cost of these multiples constitutes a very large percentage of the total cost of the board, and this cost is not justified when their maximum possible efficiency (which is low in itself, due to other factors,) is reduced by something like 85 per cent; but their omission increases operating expense, and introduces additional error, because it necessitates the trunking also of the remaining 15 per cent of calls, giving really 100 per cent trunking.

Apart from the first cost and the expense of operating, the cost of maintenance on a manual switchboard is out of all proportion to its efficiency. A vital part of such a switchboard is the equipment of cords and plugs, and the renewal of cords requires constant attention and causes continuous expense. Moreover, it needs only a moment's reflection to appreciate the effect of defective cords on total efficiency of the service, and in part on its most vital feature, that of transmission. A cord commences to depreciate the moment it goes into service, and in spite of renewals, the cords along the board can never be at 100 per cent efficiency as compared with other portions of the circuit. Inasmuch as every conversation takes place through some cord, it follows that so much of the transmission as depends upon cord efficiency can never equal that through other portions of the circuits consisting of solid wires and the good metallic contacts of well made plugs and jacks, and keys.

AUTOMATIC SYSTEM

Turning now to full automatic methods, we recognize that a number of the limitations and disadvantages of the manual switchboards are thereby eliminated, but others are added which are unavoidable, even in the best automatic systems. It is true that the full automatic system is much more flexible than a manual system could be, permitting subdivision to an extent which in manual practice is impossible, and it is also true that the operator factor is to a certain extent reduced. It is equally true, however, that there are mechanical and electrical limitations to subdivision, that a certain number of operators are unavoidable and constantly required, that the first cost and cost of maintenance of a system are considerably increased by the location of sending devices at all subscribers' stations, and that a meretricious and contradictory method of operation is adopted, which in itself constitutes not only a departure from sound fundamental principles, but also a limitation, felt in proportion to the diversity of and increase in miscellaneous traffic. To put this in a word, the human element which is indispensable to the rendition of good service, whether by mechanical or other means, is removed from contact with the calling subscriber, who is forced to do his own operating.

A certain percentage of operators have been found indispensable, however, in all automatic exchanges of any size. Pay station lines, many branch exchanges, trunk positions for branch exchanges, trunk positions for long distance, and the like, all require operators just the same as they do in the manual systems, and in addition a certain number of persons, whose functions are not always clearly suggested by their titles, are and of necessity must be employed to render first aid to the injured, or otherwise stated to connect themselves to lines which have difficulty in mechanically effecting selection of other wanted lines, and either digitally or electrically assist the switches to perform their normal functions. Off normal lamps and various types of trunk signals, when supplied, together with the keenly trained sixth sense of these persons, enable them to locate apparatus which is not properly working, and having some expert duties, it may safely be assumed that in every exchange their average pay is at least $60 per month, which is double the pay of a good manual operator.

In certain typical automatic plants, notably one serving 10,000 subscriber lines in a large city in Ohio, without any party line service, the number of these mechanicians is on a basis of one for every 700 lines. Taking these as equal to double the number of ordinary operators in point of wage, we have the equivalent of about 29 ordinary operators, serving 350 lines per operator. In addition to the automatic equipment, a manual switchboard is provided at which the operators handle private branch exchange trunks, pay station lines and the like. At all but five of the private branch exchanges manual operators are employed. The use of manual equipment supports the previous statement, and moreover the automatic equipment is concentrated, and the manual equipment is subdivided, so that to a large extent the peculiar advantages of both are lost. It should be here stated that in the plant referred to, out of 83 private branch exchanges 78 are equipped with manual switchboards handled by local operators, and only five are fully automatic.

These figures are rendered more significant by the fact that the traffic originating in private branch exchanges in any city is far in excess of the average calls per line throughout the rest of the system. Thus the largest users of the service in this system are handled by manual methods practically to the exclusion of automatic.

The sending devices or dial machines located at all the subscribers' stations in any automatic system are objectionable for three reasons: the first is the original cost; the second, added cost of maintenance and increased liability to derangement and consequent poor service due to instrument defects; and the third, the uncertainty in transmission of controlling impulses for switches, over lines of varied length and resistance, which moreover are exposed to varying external conditions.

The simplest form of subscribers' sender is a dial or equivalent key controlling a pair of contacts in the metallic circuit. It need scarcely be pointed out that this insertion of another contact in the talking circuit is in itself a detrimental feature. Passing this however, and without criticism of specific designs of senders, it may be stated that the first cost of the sender, plus the investment represented in interest by the annual maintenance charge added thereby, more than doubles the cost of the subscribers' equipment, as compared with a simple manual common battery telephone set. The increase in cost alone of a fully equipped automatic telephone over corresponding types of manual telephones is more than 50 per cent allowing nothing for added maintenance.

Again, the repeating relays which respond to line impulses and directly control the switches, must be balanced against their respective switch operating magnets. As these relays are forced to work on current impulses transmitted through lines of varied length and resistance and with many different senders, it is apparent that the working must be to some extent marginal, especially between widely separated centers.

MANUAL VS. AUTOMATIC OPERATION

The subscriber in the manual system is sold service, there being a difference in degree only and not in kind, between this service and that rendered by a messenger company. The first requirement for such service is special capacity, and for this training and discipline are both indispensable requisites. A messenger company trains its employes, and the manual telephone company trains its operators, and in addition maintains discipline almost military in its strictness. But the requirements made of an operator in handling common battery manual switchboard appliances are but little more exacting or onerous than those imposed in the handling of his calling dial and the manipulation of ringing button, on the automatic subscriber, who has no advantage of acquired poise and methodical habit, as have the manual operators. However, the question of efficiency only in the purely mechanical work of handling apparatus cannot be considered without taking into account the mental attitude of the subscriber toward an agency which has already passed beyond the realm of luxury, and become an absolute daily dependence in every function of social and business life. Taken in the mass, subscribers must, and observation shows they do, look upon the telephone company not in any case as an aggregation of mechanism, but as a responsible medium and agency to which they can safely entrust a certain portion of their business. This attitude becomes insistent as social relations become closer and more complicated with their increase. The question is therefore one of policy as well as mechanical possibilities.

For the specially trained and poised manual operator, the automatic method substitutes the untrained, undisciplined subscriber exposed to conditions so variable that they are responsible for a considerable percentage of the errors and reported troubles in even the best manual systems. Uniform and efficient operation of mechanism under such conditions is problematical, and no fair test has yet been afforded on a sufficient scale, and with a widely enough extended full-automatic area to furnish satisfactory affirmative arguments for the principle of subscriber-operation.

The saving effected in operators by the use of a full automatic system, it may safely be assumed from the facts herein stated, is only a percentage saving which varies with traffic and other conditions, but would probably never exceed 50 per cent under the most favorable conditions, even allowing for the switchboard men and other skilled employes in the manual exchange (since operating and maintenance must involve a certain amount of expense in all systems.) Against this saving are to be set interest on the extra first cost and the additional maintenance on the subscribers' instrument equipment, due to the addition of senders. This cost in a 10,000 line exchange may be estimated at not less than $25,000, and the extra maintenance charge at not less than $5,000, or a total annual figure of not less than $6,250, not including depreciation. The depreciation factor is relatively high, because the subscribers' sender is not only exposed to constant use, but unskilled use and accident as well. Reports show sender trouble as high as 65 per cent of all instrument trouble. The figure given may therefore be regarded as conservative. The salaries of 80 operators, at an average of $25 per month would be $24,000 a year, so that more than 25 per cent of the saving in operators' salaries is represented by the additional outlay for the subscribers' automatic equipment alone.

The point to consider therefore is whether a reduction in operating expense, assumed at an unabsorbed maximum of 37½ per cent, is sufficient to justify depriving the subscribers of any direct access to human intelligence, slowing down the service, rendering it uncertain, and finally removing the principal ground for confidence on the part of the subscribers. In an exchange like that above mentioned, where a large percentage of calls is handled manually in any case, the reduction would undoubtedly be much less than this figure. Another point is that the constant growth and expansion in any territory must lead to more complicated operating conditions, and a consequent increase in the percentage of enforced manual operating.

It is generally accepted by traffic men and engineers that the most important step in handling traffic is to effect quick and satisfactory initial connection of a calling subscriber with the central office agency, of whatever nature. In a manual system, it may be taken as axiomatic that if a subscriber is given quick response to his calls, subsequent delays are secondary in their effect, but delay in answering is fatal to good service, because it immediately destroys the subscribers' feeling of confidence. It is at least partly to meet this condition that the provision of the so-called mechanicians is made in the automatic exchange, which in meeting one objection creates another, because the claim of secret service cannot be supported when a force of employes is provided regularly equipped for the express purpose of listening in when the switches do not work properly. It is no answer to this objection to say that eaves-dropping is possible in any system; because unwarranted listening-in is rare where it is not within the regular province of employes, and where proper discipline is maintained. Even in the manual exchange, if the operators are required to supervise connections by means of their signals, the occasion and opportunity for eaves-dropping are lacking. Moreover, this condition is provided for in modern manual systems by means of a special signal lamp connected with the listening keys of each position, and under constant observation of a monitor. The flickering of this lamp indicates routine work, but its steady burning enables the monitor to cut in her telephone on the corresponding position and at once detect any eaves-dropping. The provision of such supervisory means for peripetetic and unattached employes would be difficult if not impossible and certainly very inefficient.

In considering this whole question of human agency *vs.* answering machine, due regard must be paid, it should be repeated, to the manifold complications constantly arising in modern traffic, which if a high standard of efficiency is to be maintained, require human intelligence. Any method which is based on the assumption of 100 per cent normal operating conditions must fail to satisfy actual conditions in practice, and even granting for the sake of argument that such normal conditions prevail in the service of business districts during a part of the time, this takes no account of the uncertain character of residence communications, where the discipline due to general business experience and training is unavoidably lacking. A calling subscriber whose condition, or environment, or time, prevents his giving intelligible instructions to an operator, in a deliberate and normal manner, would certainly not be able to operate mechanism normally. In the automatic system misguided operation must extend its effect not only to the line calling but to the lines of other subscribers, and there is no means of detection unless the subscribers who have been annoyed call in to the information operator or trouble clerk, which in the majority of cases would not be done. In a manual system, after a wrong number is called, it is apparent to the operator, either by direct report from the subscriber or by her own observation, and this enables records to be made with some degree of accuracy, as well as a remedy for the trouble applied. Moreover, incomplete or defective instructions to the operator of a manual board, due to ignorance or mistake of the originating subscriber, are at once apparent, so that the call can be blocked, and further annoyance prevented. Take another example: Peg counts have been taken where there are competing systems in the same territory, showing that it is a frequent occurrence for calls to be made over one system for numbers in the other. Where one of these competing systems is automatic, and the other manual, such calls on the manual systems are readily blocked, but there are no means in the automatic system for blocking calls for numbers taken from the manual directory.

AUTOMANUAL SYSTEM

The fundamental principle underlying the Clement automanual system is this, that the calling subscriber should be met at once by the response of a human intelligence which can direct the proper automatic agencies to satisfy his wants; or in other words, that the correct method of handling telephone traffic is to sell service, and not rent apparatus. The analogy in this respect between a telephone company and a telegraph or messenger company is striking. Each is a conveyor of communications, and fundamentally it would be quite as correct for the messenger company to rent bicycles to its patrons, so that they might deliver their own messages, as to rent mechanism to telephone subscribers for the same purpose. The analogy extends even to the point of secret service, because if it were claimed that the renting of bicycles would enable patrons to deliver their messages secretly, then this claim would obviously be defeated by the provision of a corps of trained bicyclists for the express purpose of watching and helping distressed amateurs to their destination, in order to see that each message is correctly delivered.

FIG. 1.—Automanual operating equipment—Ashtabula Harbor

Stated broadly, the automanual is a combination of the manual and automatic methods which contemplates (1) centralization of automatic apparatus; (2) the employment and concentration of operators; (3) correct subdivision of a system for traffic handling.

I will amplify these three points a little before describing a typical system. First, the apparatus is all concentrated at exchange centers, the subscribers' lines and telephones being reduced to the naked common battery type, which is the limit of simplicity at present attainable in any system. The substation construction, and the connection and distribution of lines at the exchange centers are the same in the automanual system as they are in any modern standard common battery system. The method can be applied to magneto lines if desired, but this would only be called for now in the case of rural or toll lines. With regard to the operators, I have restricted them to the only indispensable and essential function requiring intelligence, that is, ascertaining the subscriber's want, and setting up a signal by which automatic apparatus may be caused to supply that want. The regular duty of a subscriber's operator permits no departure from this rule, since even emergency calls can be handled by switching them to another operator specially provided for such duty. The automanual operator works at 100 per cent efficiency all the time, and since her duties are simple and unvarying, she has the opportunity of becoming expert, and moreover, requires no tedious or expensive preliminary training. It has been found that one day's training will suffice for an automanual operator, as against three month's experience for manual operators to produce corresponding efficiency. The actual preliminary training period, before putting the operator in touch with subscribers, is about one-half hour for the automanual operator as against three weeks for the manual operator. The

FIG. 2.—Automanual operating room—Warren, Ohio

manual operator may require additional training if sent to a different exchange in the same city, where key board apparatus is different, as well as the arrangement of multiple; special training is also required to fit an *A* operator for the duties of a *B* position, or of a paystation operator. In the automanual, the method of operating is standard in all exchanges and under all conditions.

It is possible to concentrate all the operators at a single operating center, which can take care of all the switching or exchange centers in a district or even in an entire city, handling all calls with maximum efficiency, and giving uniform service regardless of the nature of the calls, or the time of calling, twenty-four hours per day. This concentration, and the distribution of the total load over a single group of operators, without regard to where the calls originated, effects great economies by eliminating all but the summatic load fluctuations, to which the total number of operators on duty is at all times directly proportional. A farther gain in efficiency is due to better discipline and control of the operators where they are concentrated. Perfect subdivision, within physical limits peculiar to each territory served, is possible with this system, and the benefits of operator-centralization are realized regardless of the extent of subdivision. In other words, I adhere to the rule of bringing the operator into direct communication with the calling subscriber, wherever

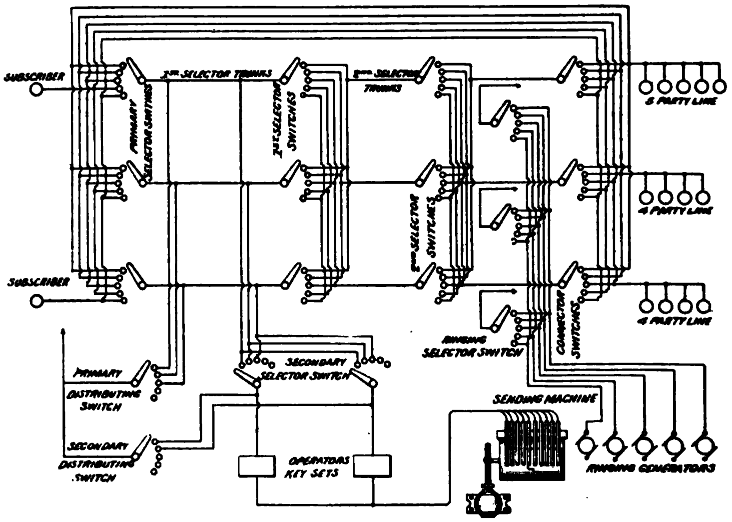


FIG. 3.—General arrangement of automanual exchange

his line terminates. Moreover, no talking trunks or talking apparatus are tied up beyond the actual point of entry of the calling line until the operator's duties are concluded. I call this a " clearing-house system ", because all traffic is handled, directed and checked from the operating center or clearing-house, without any subscriber connections passing through the operating center. The cable plant between switching centers is designed with a sole view to traffic requirements between these centers, and without any regard to the location or connection of the operating center.

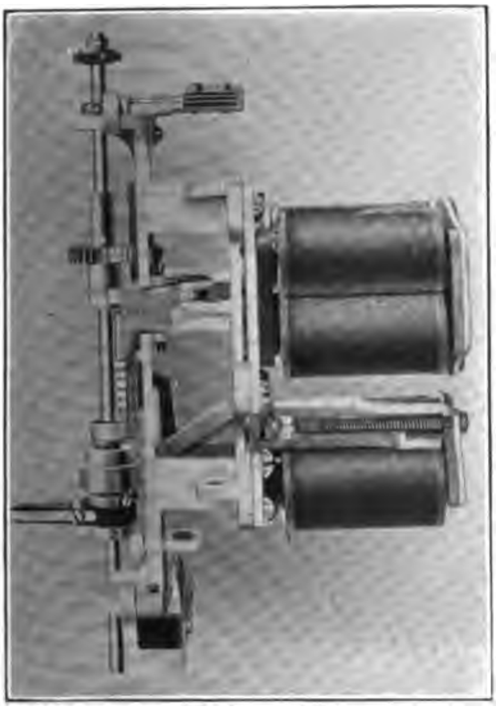


Fig. 4.—Switch

Fig. 3 is a simplified skeleton diagram showing the general lay-out of an automanual exchange equipment having a capacity up to 10,000 lines. In this diagram, five subscribers' lines are shown, one of which is a five-party line, two others are four-party lines, and the remaining two are individual lines. Ringing is supposed to be five party selective.

In this diagram, for the sake of clearness, only the most elementary forms of apparatus are shown. The switches, however, are supposed to represent two-motion, one-hundred-point, electromagnetically-driven, step-by-step automatic units, of uniform type, shown in Fig. 4. Percentage trunking is employed throughout the system shown, and the switches are equipped with banks (not shown in Fig. 4) containing ten vertical rows of ten contact pairs each. The motion is around and up, this, precedence of the rotary motion affording certain advantages, among which is the easy accommodation of row test-terminals, so that the two-motion switch can be used for primary selectors. This enables the entire system to be built up of interchangeable units.

FIG. 5.—100-line unit frames—Ashtabula

The method of aggregating units was adopted in the very beginning of my work, partly as a matter of convenience, but principally with a view to efficiency and economy in manufacture. It is followed in this manner: The individual or unit switch is composed of a certain number of interchangeable units, such as the spindle with its wipers, the frame, and interchangeable operating magnets; each switch or trunk circuit, such as the primary and first selector, the second selector and the connector equipment, is assembled complete as a unit, the latest designs having steel mounting plates upon which the unit switches with their relays, condensers, etc., are mounted and wired up complete, previous to being assembled on the racks; a sufficient number of switch plates, with the line and cut-off relays, lamp strips, and other accessories, are mounted on a frame section to form a 100-line unit; and finally these 100-line unit frames are aggregated to build up the full exchange equipment, adding thereto of course the operators' and wire chief's desks, power plant, etc. Five of these frames are shown in Fig. 5, which represents the Ashtabula equipment, with the wire chief's desk in the foreground. The operators' desks are in a separate room. Ten similar units are shown in Figs. 6 and 7, which show the Warren, O., equipment.

FIG. 6.—Automanual switch-room—Warren, Ohio., showing main frame and secondary switch panel

In Fig. 3, the circuits have been laid out so as to show in a simple way the analogy between this system and a manual switchboard system, the same operations being performed in the same manner throughout, but automatically instead of manually. For example, the subscribers' lines terminate on primary selector bank contacts which correspond to the answering jacks of the manual board, and they are also multipled to calling contacts in the banks of the connector switches, which correspond to the multiple jacks on the manual board.

The wipers of the primary selector switches constitute the equivalents of plugs which coöperate with the subscribers' answering jacks, but are mechanically driven thereto instead of by the hand of an operator. The first selector switches similarly correspond to the calling plugs of manual pairs, and the first selector trunks extending between the primary and the first selector switches are the equivalents of the cord circuits. The second selector and connector trunks are the same as trunk lines between different positions on a switchboard, the method of switching at each step corresponding to the selective insertion of another plug to add another link in the connection by a manual operator. The secondary selector switches constitute the equivalents of the operators' keys associated with the cord circuits, and the sending machine operated therethrough sends impulses to work the selector and connector switches, instead of spoken words to direct an equivalent number of successive operators. The primary distributing switch performs the function of the operator's mind in selecting an idle cord circuit for any given connection, and the secondary distributing switch is the equivalent

FIG. 7.—Automanual connecting-switch racks—Warren, Ohio., showing arrangement of 100-line units

of a monitor distributing calls among the operators, by directing each one of them when to answer.

The ringing selector switches take the place of the selective buttons of *B* or trunk operators so that the selection of the desired generator to ring a particular subscriber is directed by impulses from the sending machine, instead of by spoken words proceeding from the original or *A* operator. To complete the analogy, the releasing means for all the switches when in service are controlled by the connected subscribers, thus corresponding to the supervisory signals, by which in a manual system the subscribers can instruct the operators to clear out.

All subscribers' lines are represented by terminals in the primary selectors and in the connector banks, and while the method of trunking shown is only a contributory feature of this lay-out, the diagram will be fully described, for the benefit of those who may not be entirely familiar with this class of circuits. I might state in passing that there are a great many features of special design in the automanual circuits, but they involve so much detail that the limits of the present paper do not permit my presenting them at this time.

The progress of a call is from the calling subscriber through an idle primary selector, which becomes automatically attracted to his line, and thence through a secondary selector, similarly attracted, to an idle operator. Under no conditions is this departed from, even in subdivided systems. The principle is that the operator should be brought into direct touch with the subscriber at the very outset, precisely as in a manual system. Having ascertained the number, the operator sets up this number on her key set (Figs. 10 to 12) and sends impulses through her circuit to the first selector, second selector, connector, and ringing selector switches, thus establishing the wanted connection and also starting agencies in the connector circuit which continue thereafter automatically to ring until the called subscriber answers or the calling subscriber hangs up the receiver. After initiating the call, the calling subscriber's line is connected through the primary and secondary selector switches to the operator in every case, and, further movement of a subscriber's hook or the repeated opening and closing of the circuit, will not reach more than one operator, and cannot disturb general traffic conditions. A special busy tone-test is provided, brought into service through the first selector trunks so that it is audible to the operator when she comes in on a calling line if the calling subscriber has hung up his receiver. This happens sometimes through change of purpose or the like, and it is highly essential that the automanual operator should not experience the slightest delay, nor pay attention to anything except the rigid rule of getting the number and setting it up. After the operator has answered the calling subscriber is given full control of the connection, and can clear out and release all of the apparatus including the operator's set at any time up to the moment when the called subscriber answers. Thereafter, the called subscriber assumes control of the connector switch, which he can release so as to clear his line by merely hanging up his receiver. This prevents tying up the called line.

When the operator connects the sending machine to the switches, through her key set, impulses are sent in groups corresponding to the several keys depressed, that is to the number wanted, as well as to the number of the generator required to ring the wanted party, if it be a party-line. The first group of impulses steps around the first selector switch to pick out a group of second selector trunks, and an idle trunk in that group, leading to the wipers of the second selector switch. The second group of impulses works this second selector switch to pick out a group of connector trunks, and an idle trunk in that group, terminating on the wipers of a connector switch in whose banks appear the terminals of the wanted line. Successive groups of impulses are then transmitted to step the connector wipers around and up to the wanted line terminals.

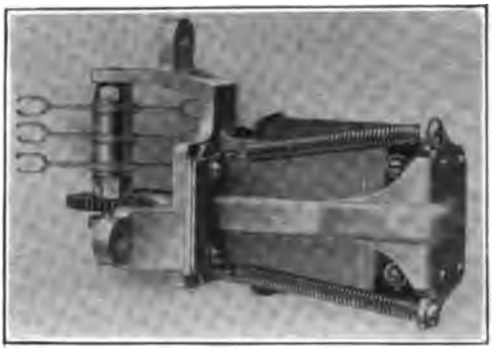


FIG. 8.—Rotary switch

Associated with each connector switch is an auxiliary or ringing selector, having a wiper sweeping over terminals which are connected to several ringing generators, as shown, each of which supplies current at a distinctive frequency. In actual practice, for five-party ringing, the frequencies are determined so that they cover about the same range as the older four-party harmonic frequencies, without the same liability to interference.

For these auxiliary selectors, in this and other parts of the system, a simple form of rotary switch is employed, shown in Fig. 8. The magnet unit in this switch is the same as the interchangeable units employed in the larger switch, and the wipers are always rotated in the same direction, being restored to normal or zero position by connecting an interrupter to the stepping magnet through a pair of extended arc contacts bridged together as long as the wipers are off normal.

At the last stage in a connection, when the wanted subscriber's line has been picked out by the connector switch, and the ringing selector has been set so as to bring into service the proper generator, that generator is then automatically and periodically connected by a ringing relay to the subscriber's line to ring his bell. At all other times the ringing selector remains disconnected.

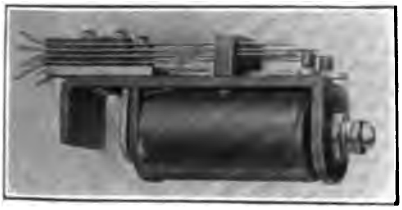


FIG. 9.—Relay

The control of the primary selector switches is through relays on the switch racks, responsive to line current. These relays complete local circuits to place test potential on the row and individual test contacts of the primary selector switches, and at the same time close starting circuits for the primary distributors which select the idle trunks and for the secondary distributors which select the idle operators. A type of relay is employed both for the lines and switches, shown in Fig. 9, which is the result of much thought and experiment. This relay has the flux bar bent over at both ends, the inner end being screwed to the rack, and the outer end carrying the adjustment for the magnet core. The bell crank armature is dropped through a slot punched in the flux bar near the rack end, and the springs are mounted on this same end, so that both the armature lever and the springs extend forwardly. This construction gives a long leverage with a very small air gap which is essential for this class of work, and also exposes the core adjustment and spring contacts.

The operation of the secondary selector switches is essentially the same as that of the primaries. As soon as the primary distributing switch has determined the primary trunk to be connected to the calling line, the selected secondary or operator's switch has its starting circuit closed, and commences to test around its row terminals until it finds the row in which the selected trunk terminal is found, and then tests up that row until it reaches the trunk, where it stops, and remains connected to the trunk until finally released in one of three ways, viz., by the calling subscriber hanging up after the operator has answered, or by the operator clearing out manually by the sending machine at the conclusion of a cycle of impulses, whereby a complete connection is established. A very distinct advantage is gained by the use of two-motion switches for primary and secondary selectors, because there being ten rows of bank terminals of ten each, the entire one hundred may be tested in a maximum of twenty steps of the switch. The interrupters and sending machine are timed so as to deliver at the rate of about one thousand impulses per minute, with the battery voltage normal. Any drop in the battery which would affect the switches is compensated by a corresponding drop in speed of the sending machine. At the normal speed stated, however, a high number line in the calling group and a high number trunk in the corresponding group, can both be found and connected in less than one and a half seconds. Where the numbers are low, the action is practically instantaneous, and it is to be noted that the primary and secondary switches are operated simultaneously, that is to say the primary is testing for the line while the secondary is testing for the trunk.

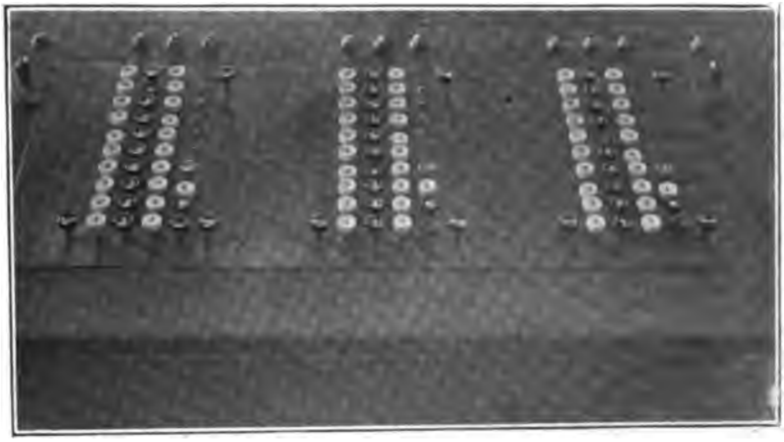


FIG. 10.—Automanual operators desk with three key-sets. Ashtabula Harbor, Ohio

Each operator has three key-sets mounted on a suitable desk (Figs. 10 and 11), each having associated with it certain signals which guide the operator in the performance of her duties. The key-set in general appearance and arrangement is quite similar to the key board of an adding machine or typewriter (see Fig. 12), consisting of a number of strips of ten keys each (see Fig. 13), numbered from one to naught in each vertical row. One of the signals associated with these keys is a calling lamp, which is lighted automatically when the key-set becomes connected through the secondary switch to a first selector trunk already connected to a subscriber's line. Observing the signal, the operator asks the subscriber for the number wanted, and proceeds to depress the corresponding keys or buttons. She then presses a separate starting key, and groups of impulses, corresponding to the buttons depressed, will thereupon be transmitted as already stated. The wanted subscriber's bell is automatically rung at intervals until the call is answered, but in the meantime it is both unnecessary and undesirable to hold the operator and so the secondary switch is cut off automatically by the sending machine as soon as the ringing starts.

FIG. 11.—Operator's desk

In practice, duplicate sending machines are arranged as shown in Fig. 14, with gang switches enabling either to be thrown in or out in case of necessity. Each machine comprises a cam drum working ten pairs of number contacts, with separate controlling contacts and a commutator. On one side the commutator is grounded and on the other connected to all of the number spring sets, and the number cams are so located that in the rotation of the drum they make and break at points of zero potential on the commutator, thereby avoiding sparking at the selective terminals. The operator's key-set is normally disconnected from the sending machine, but is connected thereto when the starting button is pressed, by means of a switch which is thereafter stepped forward one step for each rotation of the drum, shifting the connections for one key strip to the next in proper sequence.

FIG. 12.—Key board closed and open

After the whole number of groups of impulses has been transmitted, the switch is restored and the secondary selector is released automatically.

There are a great many other features which I would like to mention here, but I believe this brief description will render the general operation of the system clear and enable the tables and curves which follow to be read understandingly. It is pointed out that from the moment the calling subscriber takes down his receiver until the calling lamp lights before the selected operator, that operator has no duty to perform nor is her attention distracted. If in the course of events there should be waiting calls, they do not appear before the operators until the latter are free to attend to them, which is an important point. The instant a signal appears, however, the operator being free disposes of that call. The minimum answering time in this system is practically zero. In handling a call, the operator has only the buttons to depress, and as shown in Fig. 13, these are especially designed to require as small an expenditure of energy as possible. The swinging bar engages the locking flanges on the different key stems, but the keys are raised by light coiled springs. It is unnecessary to release a key for correction as the depression of another key in the same strip releases the one previously set.

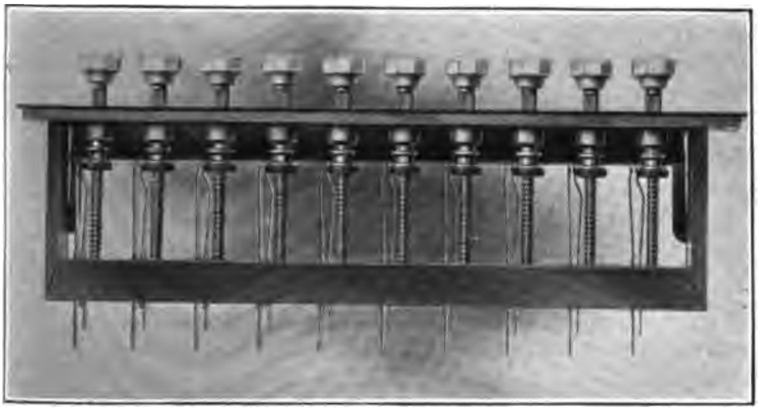


FIG. 13.—Key board buttons

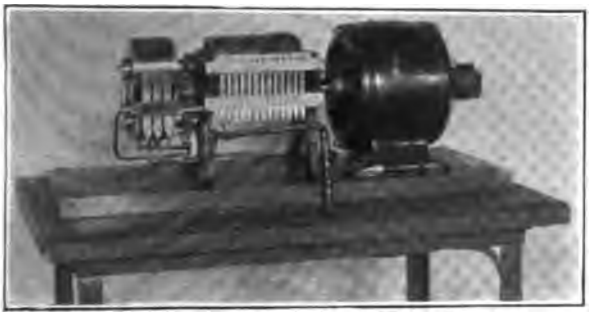


FIG. 14.—Duplicate sending machines

The description of operation which I have given applies of course to trunking between exchanges as well as to connecting lines in the same exchange. The operation is no different, since the trunks between switches may extend any distance. Obviously only one set of operators is required, because all working impulses go forward though the first selector trunks, that is to say from the operator, through her trunk to the point where the call originated, and then forward through the talking trunks or links as they are built up. Thus, no talking trunk is brought into service or tied up until it is actually required, and moreover, since the subscribers automatically release when they hang up, no trunk is tied up an instant longer than is required.

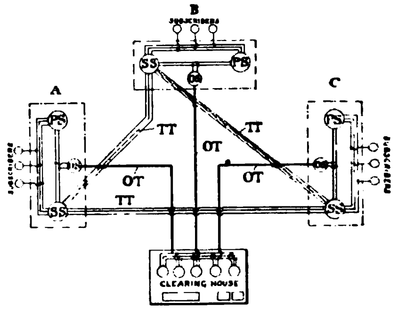


FIG. 15

Fig. 15 is a diagram showing the clearing-house connected to three exchange switching centers, *A*, *B*, *C*, directly connected by talking trunks *T T* shown in light lines, and all connected to the clearing-house by special or operators' trunks *O T* shown in heavy lines. At each of the exchange centers three subscribers' stations are shown connected to the primary selector switches *P S*, and the selective switches, *S S*. The operators' trunks have secondary selectors *O S*, containing in their banks terminals for the primary selector links. At the clearing-house the operators' trunks *O T* are arranged for automatic distribution among the operators' key sets in a manner similar to that shown in Fig. 3. It will be observed that the talking trunks *T T* between exchanges, which carry the traffic load, are absolutely independent of the operators' trunks, and have no relation whatever to the clearing-houes. The operators' trunks are worked at 100 per cent efficiency all the time, each being tied up for any call during a period of a few seconds only while the wanted connection is being established and being then free to take on another call and so on. The number of these trunks required to any switching center is proportional to the originating traffic therein, and would usually be less than one per cent of the number of lines terminating at that center. The course of a connection may be traced as follows:

Suppose a call to originate with the first subscribers' line in the exchange *A*. This is automatically connected to an idle primary selector switch, *P S*, thence through the link of that switch to an idle secondary selector switch *O S*, and an operators' trunk line $O\,T$ to an idle key set at the clearing house. Thus the calling subscriber is confronted by the operator at the instant of his access to the first piece of apparatus, that is the primary selector in his own exchange, in the same manner that he would be confronted by a manual operator physically present in that exchange. The operator in this case having ascertained the number wanted, sets it up on her key set (Fig. 12), and presses the starting key. Impulses are then transmitted from the sending machine at the clearing-house, out over the operators' trunk, through the secondary selector at exchange A, to the first selector switches of the set $S\,S$ which is permanently connected to the primary selector $P\,S$ to which the calling subscriber is temporarily connected. The impulses corresponding to the first digit of the number cause the first selector switch $S\,S$ to select a local connector or selector, or a trunk leading to the desired exchange, which we will assume in this case to be B. The trunk terminates there in a second selector switch $S\,S$ and the impulses corresponding to the next digit cause this second selector to pick out either an idle connector containing the line wanted, or an idle third selector through which the connector can be found by a fourth set of impulses, depending on the size of the exchange B. As soon as the connection is completed, that is to say, as soon as one complete cycle or set of impulse groups have been transmitted from the sending machine, its connection with the operators' key set is automatically opened, and the secondary selector $O\,S$ at the originating exchange, A, automatically drops off and disconnects the operators' trunk, being immediately thereafter available for another call. Thus, the operators' function having been fulfilled, in accordance with the rule hereinbefore stated, with the least expenditure of time or energy by the operator, she is instantly relieved, free to take another call, and the control of the connection through the talking trunks and switches remains entirely with the connected subscribers. When they hang up their receivers, all the switches are instantly cleared out, and ready for further use.

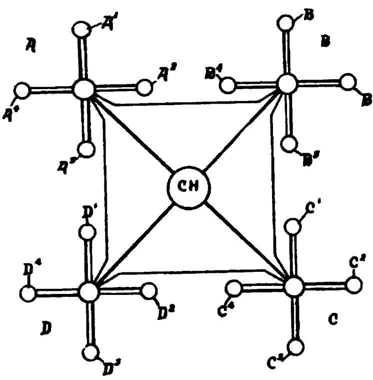


FIG. 16.

Fig. 16 shows the clearing-house principle applied to a sub-divided system having four districts, *A B C D*, the first of which has sub-centers *A*1 *A*2 *A*3 *A*4, the second sub-centers *B*1 *B*2 *B*3 *B*4, and so on. The clearing-house *C H* is connected through operators' trunks *O T*, to the district centers and thence to the sub-centers, the method of handling calls being the same as that explained in connection with Fig. 15.

COMPARISONS OF SYSTEMS

In order to arrive at a true comparison of the actual labor required of the manual and the automanual operator in handling a call, the following analytical tables have been prepared, giving a unit energy value to each of the different movements required of each operator and assigning that value in accordance with the judgment of traffic experts.

TABLE OF COMPARATIVE WORK UNITS BASED ON NUMBER OF MOVEMENTS OF AN "A" OPERATOR IN HANDLING A LOCAL CALL

		Manual	Auto manual
1.	Operator to note line signal	10	3
2.	" insert answering plug	50	0
3.	" " open key and say "number"	30	5
4.	" " pick up calling plug	30	0
5.	" " reach for and test multiple	75	0
6.	" " insert calling plug	50	0
7.	" " close key	25	0
8.	" " set up number	0	25
9.	" " ring called party	15	0
10.	" " press starting button	0	5
11.	" " observe disconnect signal	10	0
12.	" " disconnect both cords	75	0
	Total	370	38

EXTRA MOVEMENT OF "A" OPERATOR IN HANDLING A "B" CALL

		Manual	Auto manual
13.	Operator to depress order wire button	15	0
14.	" " ask for trunk assignment	30	0
15.	" " depress branch exchange button	0	5
	Total	45	5

MOVEMENT OF "B" OPERATOR IN HANDLING A CALL

		Manual	Auto manual
16.	Receiving order for trunk and assigning same	15	0
17.	Observing and assigning idle trunk	15	0
18.	Pick up trunk assigned and reach for multiple	100	0
19.	Test multiple jack	10	0
20.	Insert plug in multiple jack	50	0
21.	Ring called party	10	0
22.	Observe disconnect signal	10	0
23.	Take down trunk	50	0
	Total	260	0
	Grand total	675	43

It will be noted that in the handling of a purely local call the manual operator is represented in 370 work units as against

38 work units for the automanual operator while in the handling of a trunked call the manual operator is represented in 675 work units against 43 for the automanual operator.

In addition to the foregoing comparison of mental and muscular effort, it is possible to represent in foot-pounds the work done in lifting the plugs, cords, and weights, overcoming the friction of the cords against their associated plug seat walls. In one thousand completed connections and disconnections, about 2,917 ft-lb. of energy are expended by the manual operator, that are not required and are not expended in the corresponding work of the automanual operator. The manual operator may average 250 calls per hour, but the automanual operator easily handles 1000 calls per hour, so that a saving of 2,917 ft-lb. per hour must be credited to the automanual system. This is presented as evidence that my purpose of relieving the operator of all unnecessary work is fully accomplished. I believe this saving is translated directly into terms of higher efficiency, not only increasing the number of calls handled, but cutting down the percentage of error by the lack of strain on the operator.

The following tables represent three sets of service tests made on a commercial automanual switchboard under actual operating conditions. Each test represents the total time consumed by the operator in observing the call, depressing the listening key, pronouncing the word "number", repeating the numeral as it is given, setting up the same on the key set, and finally depressing the starting key. It should be particularly noted that this is *total* time per operator call, and not merely answering time, which is what the manual companies usually give.

First 100 Records

Longest	individual period				12.40	sec.
Average	five	longest	individual	period	7.44	"
"	ten	"	"	"	6.34	"
	Shortest	"	"		1.60	"
"	five	"	"	"	1.92	"
"	ten	"	"	"	1.96	"
"	entire 100 records	"	"		3.396	"
	Hourly rate at which calls were being handled				1060	

Second 100 Records

Longest	individual period				7.60	sec.
Average	five	longest	individual	period	5.52	"
"	ten	"	"	"	5.34	"
	Shortest		"	"	2.00	"
"	five shortest		"	"	2.04	"
"	ten	"	"	"	2.18	"
"	entire 100 records		"	"	3.374	"
	Hourly rate at which calls were being handled				1067	

Third 100 records

Longest individual period	5.40	"
Average five longest individual period	5.32	"
" ten " " "	4.44	"
Shortest " "	1.60	"
" five shortest " "	1.65	"
" ten " " "	1.80	"
" entire 100 records	3.16	"
Hourly rate at which calls were being handled	1139	

The first and second records were made by the same operator, and the third record by another, but neither of the operators knew that the record was being made.

These are not selected records but are all of the records made on the same day and all represent actual calls.

COMPARISON OF MANUAL AND AUTOMANUAL OPERATING FORCE

A comparison between a manual and an automanual operating force in handling a traffic load is shown in Fig. 17. This traffic load represents 4162 working lines connected with a main and a branch exchange located in a western city. About 21 per cent of all calls (flat rate) are trunked. The calls handled during the busy hour in both exchanges average about 185 per manual operator.

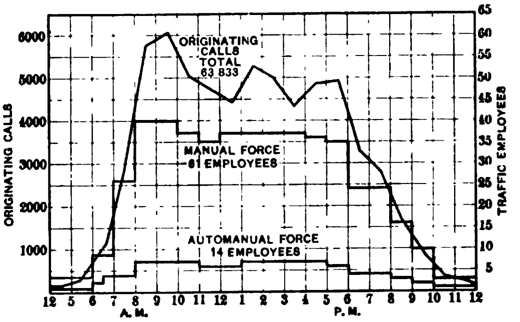


FIG. 17

THE MANUAL FORCE	THE AUTOMANUAL FORCE
2 chief operators	2 chief operators
1 information operator	1 relief operator
5 supervisors	11 operators
3 relief operators	—
50 operators.	
--	14 employes.
61 employes	

It will be noted that the manual " B " or trunk operators and the trunk calls are omitted from this chart. The automanual makes its greatest saving where branch exchanges are employed; the heavier the trunking, the greater the saving with automanual because it eliminates trunk operators. Notwithstanding that the chart deals only with " A " operators, a reduction in employes in favor of automanual amounting to 77 per cent is nevertheless effected.

COMPARATIVE COST IN HANDLING MANUAL TRAFFIC

No plan is known to me that has been utilized heretofore between manual operating companies in comparing their costs of handling traffic. The factors which seem to have precluded such comparison are:

1. Variation in salaries.
2. Variation in trunking percentages.
3. Variation in calling rate per line.

The only basis used for calculating traffic costs has been:

Cost of handling traffic per line.
Cost of handling traffic per station.
Cost of handling traffic per 1000 originating calls.

The first two cannot be considered as they are not based on volume of traffic handled. The third could be used for a system having a single exchange, but would be unfair to a system having more than one exchange because neither the trunk operators nor the traffic they handle is taken into consideration. Thus a system trunking 50 per cent of the calls handled would suffer in comparison to a system trunking only 25 per cent of calls handled.

The plan of equating calls has been used for comparing separately the equated calls per *A* operator hour and equated calls per *B* operator-hour in different systems, but no plan of equating both *A* and *B* calls to a standard unit has ever been used, to my knowledge.

COMPARATIVE MANUAL AND AUTOMANUAL OPERATING COSTS

Figs. 18 and 19 are compiled for the purpose of comparing costs in handling traffic, as between the manual and Clement automanual methods, regardless of variations in salaries, trunking percentages or calling rate per line. These tables are based on the rendition of a four second answering service in the manual systems and a three second service in the automanual system.

A standard unit is necessary by which every manual system may be measured and for this unit is employed the flat-rate non-trunked call as it appears in a common-battery multiple switchboard, and for convenience in comparison the cost of handling 1000 such calls is used as a basis.

Calls other than flat-rate, non-trunked calls require equalizing in accordance with the ratio of effort and time consumed, which is easily accomplished by the use of the multiplier given on the left margin of the curves shown in Fig. 18, as indicated by the point of intersection between the curves and the vertical line corresponding to the previously determined trunking percentage.

Having equalized the calls in accordance with the tables, then divide the total present daily operating expense by the number of such daily equated calls and place the decimal point to show the cost per thousand equated calls.

A comparison can then be made between the cost per thousand equated calls thus arrived at and the cost shown in curves of Fig. 19. At a first glance the multiplier of 95 for incoming trunk calls appears to be rather high but this is explained by the unavoidable loss in efficiency of a trunking operator during evening and night hours.

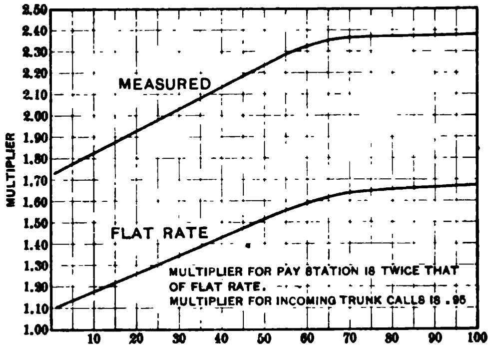


Fig. 18

A hypothetical example of a telephone system having two exchanges, shows equated calls for the following daily traffic.

Main	Exchange	130,000	flat rate calls, 5 per cent trunked	148,200
"	"	3,000	pay station calls, 5 per cent trunked	6,840
"	"	6,500	incoming trunk calls	6,175
Branch	"	12,000	flat rate calls 50 per cent trunked	18,000
"	"	200	pay station calls 50 per cent trunked	600
"	"	800	measured calls, 50 per cent trunked	1,800
"	"	6,650	incoming trunk calls	6,317
			Total equated calls	187,932

Fig. 20 shows an automanual schedule applied to the branch exchange of the western telephone company previously referred to and proves out the automanual cost curve in Fig. 19. It will be noted in Fig. 20 that the cost per thousand calls on the automanual operators' schedule is 19.5 cents. By referring to the cost curve in Fig. 19 it will be observed that the cost per thousand automanual calls is 19.5 cents where the average operators' salary is $25.00.

The clearing-house principle illustrated in Fig. 15 is applicable to existing systems, with practically no rebuilding except that of the central office switching equipments; the subscribers' instruments and lines, as well as the general method of handling the subscribers, remaining unchanged. The particular feature which renders this possible is the automatic secondary distribution, which brings calls to the operators at one or more centers without the necessity of massing or concentrating talking trunks. This feature is peculiar to the automanual systems, and the economies flowing from its employment may be best illustrated by presenting an extreme case involving the handling of the entire traffic load in a large city, at present divided between two competing systems both equipped with manual switchboards. The two systems may be designated as A and B, and the following tables are based on an actual study of their traffic conditions in detail. Table 1 shows the number of telephones in operation in each system, the approximate traffic handled by both companies, and the cost of handling the traffic. Table 2 shows the estimated increase in traffic of both companies as well as the additional cost of operating, if manual trunk lines were connected between two systems, permitting a general interchange of

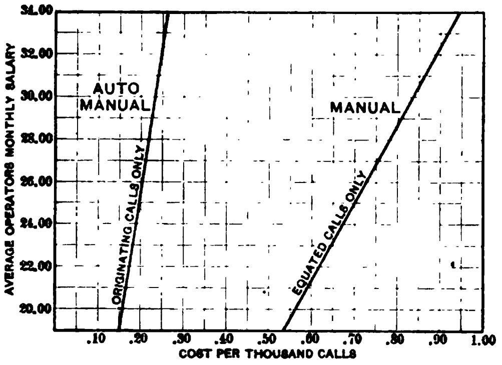
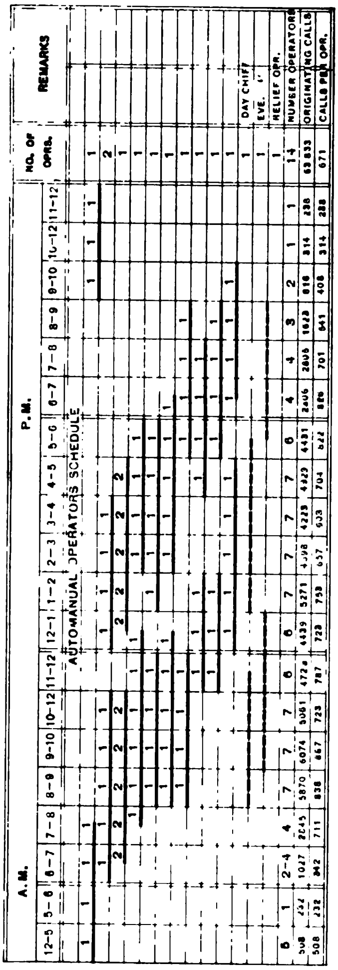


FIG. 19

calls. Table 3 shows the cost of handling the combined traffic by automanual clearing-house methods exclusively.

The automanual service is uniform and accurate, because the switching apparatus is all operated over local central office circuits of uniform and known resistance, by expert operators under proper discipline. The benefits of the manual method of operating are preserved, but no cords or plugs are employed, and the service is secret because the operators are cut off automatically when connections are established, and have no way of cutting in on any connection thereafter. The distribution of



Number of lines working, 4162; calls per line, 15.5; 14 operators at $25.00 per month, $350.00; 63,833 originating calls × 28 days (26 week days and 4 Sundays) = 1,787,324; monthly originating calls + into total monthly operating expense, $350.00; =19.5 cents per 1000 calls.

FIG. 20

calls among the operators is uniform, and this condition prevails at all times without regard to the number on duty. Each operator's position has a jack containing contacts for the telephone plug and associated contacts for the secondary control circuit of each key set at the position, these being opened when the operator pulls out her plug, so that calls come only to those positions at which operators are actually present and ready to handle them. All other positions are dead, and the calls come to the live positions in rotation. An operator may take calls at any position, by simply plugging in there and light loads can thus be handled at a single position. Patrolling of the switchboard is avoided, and as the number of operators can be varied in direct proportion to the load, no one operator is busier than an other at any time.

TABLE I.—PRESENT CONDITION

	System A	System B	Total or Av.
Number of subscribers' lines	18,666	13,219	31,885
" " " telephones	42,000	27,000	69,000
Percentage of telephones to lines	2.25	2.05	2.16
" " business telephones	54	51.5	53
Employes traffic department	498	320	818
" average monthly salary	$32.50	$31.50	$ 32.11
Monthly operating expense	$16,185	$10,080	$26,265
Originating calls daily	294,000	216,000	510,000
" " " per telephone	7	8	15
Percentage originating calls trunked	57	24	43
Cost per thousand originating calls	$1.97	$1.67	$1.84

TABLE 2.—INTERCONNECTION

Increase in calls per telephone	1.9	3.1	2.4
Calls to other company	79,800	83,700	163,500
Increase in percentage of originating calls trunked	9	21.2	14
Additional employees	153	168	321
Increased monthly operating expense	$5,184	$5,292	$10,476
Increase in cost per thousand calls	0.27	0.13	12
Percentage of increase in pay-roll	32 per cent	52 per cent	40 per cent

TABLE 3.—AUTOMANUAL

The cost of handling the combined traffic of both systems amounting to 673,500 originating calls per day with the Automanual-clearing-house system based on an average operator's monthly salary of $32.00 would amount to twenty five cents (0.25) per thousand calls, on a monthly operating expense of $5,051.25. *This makes a reduction in the present operating expense of* 86 *per cent.*

The operator cannot show favoritism, as without special provision she cannot know who originates a particular call, and any subscriber's call may be answered by any operator in the exchange. There is also a decided economy in the matter of space, the size of the operating room being considerably reduced. As regard material for operators, which is a consideration of moment in some parts of the country, it is pointed out that any person who can hear numbers and touch keys is capable of handling traffic automanually. This includes the blind, who make very efficient operators, not only handling the number keys dextrously with little practice, but also reading the lamp signals by touch. I have provided a special signal for the blind, however, so that for them lamps are unnecessary, and may be relegated to the monitors, unless they too are blind.

As the detailed circuits are not described herein, I will state that the talking circuit between subscribers when connected, is perfectly clear and in fact identical with the standard bridged common battery circuit employed in modern manual exchanges.

In closing, I wish to acknowledge my indebtedness to Mr. John P. Boylan, of Cleveland, Ohio, for his assistance in compiling traffic data for use in the preparation of this paper.

Discussion on "New Automatic Telephone Equipment," and "The Semi-Automatic Method of Handling Telephone Traffic," Los Angeles, Cal., April 26, 1911.

J. W. Gilkyson: Being responsible for the revenue produced by the manual system of this town, I hardly think it is incumbent upon me to discuss, or at least in any way to malign the competitor of the automatic. It has many phases which meet the requirements of the community. I hope, though, that in the future the semi-automatic will be the neutral factor in bringing together both the manual and the automatic. and I cannot help but think that will be the final result. The fundamental thing is economy—economy in central office operation, economy in central office equipment costs, the elimination of sub-exchanges, and the facilitation of the trunking appliances.

Mr. Keller: Regarding the automatic and manual service, I will quote from a letter I received from Europe from a friend of mine, who went to Berlin, Germany, to promote and build an automatic system. There are a few passages that are exceedingly interesting. Before going to Germany, he came to Los Angeles to see what we had, he returned by way of San Francisco. There he says, he changed his mind somewhat on one phase of the automatic feature, namely, the secondary line switch. In our automatic system here, each subscriber has one individual line switch, and we use secondary line switches to a very limited extent—not at all in connection with the subscriber's line. But in San Francisco, each subscriber has one individual line switch, and before the individual line switch reaches a first selector switch, it passes through a secondary line switch which reduces the number of first selectors to a minimum.

Mr. Luberg has always been opposed to this, but he says since looking into it very carefully in San Francisco, he has changed his mind and he finds the secondary line switch is working very satisfactorily. If he is right, I am inclined to believe it will do a great deal towards simplifying the apparatus in general use.

He says further that at Hamburg he saw in operation there a 40,000-line central exchange under one roof and it is now being enlarged to 80,000 lines. He states that it is a manual distributing system, which means that the call comes in at an A board where one A operator is provided for 800 subscribers. This operator has nothing to do but to extend the call to a B operator who answers the call. The B operator again extends the call to a C operator in the wanted 10,000 group. C has the multiple. After extending the call the B operator is cut out of the connection. The service is supposed to be fine. Referring to the cable service he mentions here that it is frightful. He says the average cable length for a subscriber is three and one-half miles.

Further on in his letter he asks what our average is. I have not quite arrived at my figures yet, but in our Olive Street exchange we find it is about a mile.

"Just now," he writes "we are installing a half-automatic exchange in Amsterdam. By the term 'half automatic' we mean a system similar to the Clement Automanual, *i.e.*, the subscribers station is the usual C. B. manual apparatus. When the subscriber calls he gets a connection first with an operator who sets up the connection with a push button keyboard. After the impulse machine has run down, the operator cuts off again. The switches are absolutely identical with the regular automatic outfit."

He says that the engineers of the German government, for as you all know, the postal authorities handle the telephone situation throughout Germany, deliberately put in this half automatic system with the intention of putting in a full automatic later on. He says the only reason that they do not make this change now is because of the cost of the calling device which is estimated at about five dollars more than the ordinary telephone instrument. Otherwise, they would make the entire installation automatic at present. Whenever they want to change their apparatus to automatic they can do so.

That looks to me like a very sensible method. If they must have a full automatic they can do so without any extra expense in the installation—that is without any waste.

It seems that the government engineers have decided that measured service should be furnished where a manual exchange is in use, and a flat rate with automatic. They take the stand that it does not cost materially more for a man to have many calls over an automatic phone than it does for a limited number of calls, while with a manual board the expense of operating increases in proportion to the number of calls, which we all know to be a fact.

"A Dr. Steidle, in Munchen, has designed what he calls 'automatic group systems.' About twenty to forty subscribers with very few calls per day (metered service) say about two to three calls per day, are connected to a relay switching station located in the basement or attic of the house, or placed in the near neighborhood. The relay combination gives access to one of the two exchange lines. In the exchange the calls are handled manually at present. Calls to the group line are distributed by 40 point connectors, also placed in the relay groups. He figures for a 20,000-line plant about 6000 heavy talkers with individual lines, and 1000 relay groups with an average of 14 lines attached to each. He therefore would provide 1000 relay groups with 1000 batteries. Now, don't smile at that, they actually put in about 60 of such groups, in and around Munchen.

"So you see we Germans just at present have the two telephonic extremes—an 80,000 line single exchange and a thousand fold subdivided plant seriously proposed by a very fine telephone engineer."

I should not wonder if we may have a similar situation to face sooner or later. Personally, I cannot say anything about half automatic, for several reasons. In the first place, I don't know much about it, but it seems to me that if the half automatic is used as a step forward toward a full automatic, that it is the proper step to take, but it also looks to me that if one cannot change it to a full automatic it is a step only half forward. It is just like changing from a horse car to a cable car—a sort of step between. Now, if that step between is a step toward making it a full automatic, I think it is a step in the right direction. I think that the full automatic will soon be the only factor in the field.

K. B. Miller: The idea suggested by Mr. Keller of using the semi-automatic as a stepping stone to the full automatic is one way of looking at it. The probabilities are that the one controlling factor in the matter, a factor which is likely to be more and more a controlling influence, is the atittude of the public. The fact is that the telephone companies are serving the public and it is the public that must be pleased. Now, my experience so far, has shown me that either the automatic, where the subscriber spells out his own connection with his finger, or the manual, where the subscriber merely asks for what he wants, is capable of giving good service, and either of them is capable of satisfying the public.

It is often argued that the automatic's success in pleasing the public is transitory– akin to the liking of a child for a new toy. I have studied that phase very carefully and, while I know that some of you will disagree, I can only arrive at the conclusion that, at present, the public will be satisfied with either way of doing it, provided good service results, and we all know that good service may result from either method. The atittude of the people may eventually swing one way or the other or it may split and result in two permanently disagreeing factions. There seems to be nothing impractical in the idea of the combinationof the two schemes, giving automatic instruments to those subscribers who want them, and connecting these directly with automatic switches; and giving to those subscribers who want to feel an operator at the other end of the line, no automatic transmitting devices, but merely ordinary telephone instruments, practically along the lines of Mr. Clement's system. The same automatic switchboard would make all the connections and disconnections, these being controlled directly by the subscribers in the one case and by the operators in the other.

A. H. Griswold: I was very much interested in Mr. Winston's last paragraph, which is one of the strongest in his paper.

"The man who attempts to prophecy what the future equipment will be, is putting himself up very much as a prophet."

In comparison with many of the other sciences, we have had rapid changes of type of telephonic equipment, and certainly we will have in the future a great many more changes before we approach the ideal.

In the final analysis, the primary thing that we must strive for is service that is reliable and efficient, and therefore service that the public desires. It may not be possible to combine in one system a type of service that will meet the desires of all of the people. There may be room for two classes of service, just as there is for the electric car and the steam car, one may offer advantages that the other does not. The thing, therefore, that must be studied is what the public wants. It may not be determined by engineers particularly, any more than to establish these various systems and try them out. It may not necessarily mean the most beautiful piece of mechanism, or the most rapid service, but it will mean the most reliable and most efficient service.

Most of us in using the telephone, if the service be reasonably reliable and the speed of answer be reasonably fast, do not worry very much about the time interval.

The proper equipment in the future may be manual, full automatic, the so-called semi-automatic, semi-manual, automatic distributing system, or some other type, but what ever it is we must have the first considerations fulfilled, that it must give reliable and efficient service, and service that the public desires. Having these first requirements, the secondary consideration, and one which I sometimes think we let precede the first, is the question of providing the best type of equipment at the least ultimate cost, meaning not only initial cost but resultant and subsequent charges.

It might be interesting to know if Mr. Winston in his automatic distributing system has made any provision for reverting calls. That is, when one subscriber calls another subscriber on the same line.

K. B. Miller: In connection with the reverting call proposition, I agree that we ought to hear from both these gentltmen about it. The reverting call is a pretty mean thing to handle with the manual system, as we all know. It seemed at first wholly impossible for an automatic system to take care of it, and yet automatic systems have been made to do this in an even more direct way than the manual.

A. H. Babcock: The automatic and the semi-automatic telephone systems appeal to me from the standpoint of the man who pulls the switch at the subscriber's end. In other words my mind at present is concerned entirely with the subscriber and not with the engineer who is constructing these things. I have a feeling after seeing the inside of one purely automatic telephone system, and having had it very fully explained by the engineer who installed it, that if there is a failure on my part to receive connection with the number that I want, it is due to my failure in handling the apparatus, rather than to the failure of the apparatus itself. Consequently, when I am asked to use a telephone system wherein I give an operator the number that I want, and she does then that which I would do, which is, I understand, the semi-automatic system, it is merely introducing another link and a very weak link into that chain.

I call a number in San Francisco very frequently. Five, six or seven repetitions of that number have been made repeatedly, and they are spoken distinctly into the telephone, too. I can't see from the subscriber's standpoint what there is to be gained by putting that extra link into the chain. I prefer a piece of mechanism handled by myself, rather than the intervention of an operator who may be tired, may not be well, may be thinking of other things—the human element, entering in all the time between what I want and what I get. In other words, the nearer we get in all our public service work, to a piece of apparatus directed by one person, the nearer we will come to getting satisfaction. Now, remember, I am speaking merely from the subscriber's and not from the engineer's point of view.

Ralph W. Pope: I wish to call attention to one of the features of the manual system, which is the only system used in New York City, that does not appear to have been considered in these discussions. I refer to the distinction between the individual subscriber working direct with the central exchange, and the subscriber working through a private branch exchange. I understand that in New York City the growth of the private branch exchanges has been very large, and where the service is sufficient to warrant it, is always preferred. I have had both experiences. Formerly, until four years ago, we worked direct with the central exchange. For the last four years, we have worked through a private branch exchange. The service through the private branch exchange is far more satisfactory, for the reason that the operator is more in sympathy with the business, pays more attention to the calls, and is apparently not overworked. That is to say in our particular exchange there always appears to be a little margin of leisure, so that the number can be repeated back, and the operator will not get away from the instrument before the subscriber has an opportunity to correct the number if wrong. When the number is repeated back direct from the exchange, half the time I can't understand what it is, and if I do and it is wrong, the operator is gone before I can make the correction. That is not true of the private branch exchange. This leads me to corroborate Mr. Gregory's statement that what we want is not so much rapidity of service, as reliability of service. There is loss of time, no doubt, in handling a call through a private branch exchange, but then there is also a gain in comfort. In working with the central exchange, we are expected to keep the telephone to the ear until the final connection is made. With the private exchange, the number is given and the telephone hung up and when the connection is made the operator rings up and we go ahead with the work. In other words, we don't have to wait with the telephone at the ear while the connection is being made. That is to me a very satisfactory arrangement, through the elimination of being obliged to sit and wait for what may be a quarter of a minute or half a minute or a minute, with the telephone at the ear. I may say right here that while I do not use the central office connection regularly, sometimes when I am in other parts of the city where I have to call up the central office and do this waiting, it is especially annoying. This all tends to bring in another feature in the telephone service, and that is the comfort of the subscriber. Mr. Babcock admits that he gets irritated. Subscribers wish to eliminate all the trouble possible, and one of the principal virtues of the common battery system is that it has eliminated the necessity of turning the crank. We simply go through the motion of taking up the telephone and putting it to the ear, and then if you simply hang it up and wait until your bell rings, you know that you have your connection.

J. W. Gilkyson: I wonder if a comparison has ever been drawn by Mr. Babcock with reference to the number of mishaps that he might have with the automatic in placing a call himself. He does not charge that error up to himself. He simply hangs up and tries it over again. He may do it two or three times, while he immediately becomes provoked at the manual operator that mistakes his number.

With reference to the private branch exchange, that is a question that we have had considerable difficulty in handling. In many instances, operators are employed by the parties served with the private branch exchange service; many of the young ladies receive a box of candy, etc., from certain individuals of the corporation and get excellent service from the company. On the other hand, the man that is abrupt, gets poor service. I believe if the standard of the private branch exchange could be adopted by the company that there would be a more uniform service. I don't think Mr. Pope's would be better or worse. That is a condition that exists. He speaks about placing his call with the operator. She performs that function that ordinarily a man on a direct connecting line would have to withstand. If that line is busy at the time he calls, he is told the line is busy. The operator has performed that function, and he has to wait. Where would the private branch exchange differ if he gets the report that it is busy? If the private exchange gets a report that it is busy, she makes a note and calls it at another time, and the connection is put up, and the man who is busy, figures it out as an excellent service, but he does not perform the function himself. It is the duty of the girl that operates the private branch exchange, which, of course, could not be expected in service given to the public, and could not be taken into consideration.

A. H. Babcock: I yield to no man in my respect the telephone operator as a woman earning her own living. I find no fault with the operators, because I know of some of the conditions under which they work. I have a great respect for their astounding skill by which they handle an immense number of calls per hour. But I do find serious fault with the condition that produces the situation I have just outlined. My conversations referred to are with a private exchange operator who is on our own payroll. I hear her struggling with the central office to get that number straight, and when I say that the number called for has been twisted out of shape six or seven times, it is by skilled operators whose business it is to handle those calls—not between me and the operator, because our private exchange operator knows perfectly well what number I want. It is not my grief, except as I have to wait, but it is hers. It seems to me the farther we can get away from that kind of thing, the better. I don't think it is fair for Mr. Pope to compare his present easy time, pushing off his job of making a telephone call onto his paid operator, with the troubles a subscriber has who cannot afford, by reason of his small service, to hire and pay a private exchange operator. The condition to be met is to give good service to the greatest number—not to a few of us who have private exchanges, or who can send boxes of candy to the operator. Possibly if the telephone expert who has just made the suggestion that a box of candy would improve the service, had realized the implication contained in that suggestion he would have expressed his thought differently. A Public Service that requires lubrication by means of boxes of candy needs some intelligent reconstruction.

F. C. Newell Jr.: Mr. Babcock has just stated that the public is really the supreme court in this case. In cities like Chicago and New York, where there is a great foreign population, the numerals are a sort of universal language. When the operator cannot understand the foreign tongue, it seems to me the numerals are to be preferred. I would like to have somebody state the advantages and disadvantages of the foreign population.

K. B. Miller: In France, I am informed by some of the foremost French telephone engineers, they consider that very point as one of the strongest arguments for the automatic. It seems that the French language, with which I am not familiar, does not lend itself as readily to the spelling out of the digits of a number as our language does, and that as a result there are a great many more misconnections, and a great slowing down of the service. That appears particularly in the trunk operations where an A operator passes a connection on to a B operator. The difference between the number of calls that a B operator can handle in France with the same type of equipment, and that which we handle in this country in manual exchanges, is remarkable, and I have heard it attributed mainly to that fact that the French language does not lend itself so readily to the transmission of numerals. Undoubtedly other factors enter also.

A. H. Babcock: How about the Chinese exchanges? Is there anybody from San Francisco who can give the experience with them?

Mr. Keller: The Chinese in this city have a private exchange of their own, or, rather a small exchange with a Chinese operator, who speaks English and establishes the connection for the Chinese. They have not yet adopted the automatic in this city. In San Francisco, however, they have adopted the automatic system, the automatic calling device with Chinese numerals on it instead of the numerals we use, and operating exceedingly successfully. In fact, it has been more generally accepted by the Chinese in San Francisco than by the general public so far.

There is another feature that I have just been told of by a young man that came from Havana. In Hanava there are a great many languages spoken, and the automatic there has become very popular on account of the fact that all of the various nationalities can secure their parties without having to converse with any operator or any other person except the party they are calling.

Ralph Bennett: I am very much interested in the four-party line. We have one at our residence from the old company, and I have discovered that I hear not only our own but all the neighbors calls from both sides of the line.

Very frequently they ring on our line, one bell, and after ringing awhile we answer. " Central wants the party whose ring is two bells," When told so she says. " Oh, I didn't know that. They didn't tell me that." It seems to me that this difficulty can be readily corrected on an automatic where the subscriber rings the correct call automatically.

K. B. Miller: It is a simple matter to have selective ringing on party lines in manual systems. Several successful schemes are available.

W. D. Moore: We maintain in our system what we call an observation desk. It means that the service we give is constantly under observation. This observation desk indicates the moment the calling subscriber takes the receiver down; the moment the operator plugs in to answer; the moment she rings; the moment the called for subscriber takes the receiver down to answer; the moment he hangs up; the moment the disconnection is made. This action is automatic—we do have a little automatic—and different colored lamps indicate the different movements and it is recorded as the action takes place. Now in each exchange there are so many observations taken each day. That is the way we determine the standard of service that we are furnishing. It also indicates the efficiency of our operating force. We figure that any operator—that is, the answering operator—can handle, during the busy hour of the day, the peak of the load, approximately 265 calls. That is, she can finish 265 calls. Now if we find there is a falldown in the service in any particular exchange, by referring to the peg count, which is taken on the tenth day of each month, we note that the operator has become loaded down and a redistribution of lines is made throughout the entire number of operators and the result is, of course, a natural improvement of service. We also have certain methods by which we procure increased efficiency from the operating force. Of course this is all worked out upon what our experience has shown us that one operator can handle without an excessive strain.

Our figures showed for this city—the last time I heard them quoted, which was some six months ago—that there was one-tenth of one per cent of the entire number of completed connections that were rung in error and this is a very small fraction of the total number of calls.

That is taken from the observation service. We can tell at any period of the day, any hour, just what class of service we are giving in a particular exchange, in a particular town or territory; and the figures have shown that one-tenth of one per cent of all the calls completed were rung in error. So, as to that part of the manual system, some particular fault of the automatic can also be found to offset it.

It appears to me, taking the subject as a whole that it is as Mr. Griswold said when he referred to the last paragraph of Mr. Winston's paper that he sums up the entire proposition in a few words. He said that it is probable that before many years the differences of opinion which now exist as to the relative advantages of manual and automatic will disappear, and that definite standards will be adopted for the various conditions of practice. There is no question about that. I believe all telephone engineers agree that we can predict that without fear of being contradicted.

Mr. Clement described his semi-automatic system, but as I have not read his paper through, I could not grasp the full details, but I believe, just speaking for myself personally, that this is the eventual outcome. I might also refer to a remark of Mr. Keller He said that the semi-automatic would be, or could be used as a stepping stone to the full automatic and that if that could be done, it would be very desirable. I believe that what he was thinking of was the saving that could be made by deferring the expenditure necessary for substation equipment to some future period. It is my opinion that is not what is going to happen in the future. I think that the automatic will be the stepping stone to the semi-automatic for this reason—you know that recently there have been certain laws enacted which prohibit the employment of female labor for more than eight hours out of any twenty-four. This places a burden on the smaller towns and exchanges. In a large city where there are some very busy people, such as railroads and other large offices, using the telephone constantly, the amount of work that the subscriber must do to secure his connection is an important factor, whereas in a smaller town it need not be given consideration, as there are no large business houses using the telephone at a very rapid rate. Therefore it appears to me that the automatic will ultimately be used for furnishing service in smaller towns, say up to a capacity of 1,000 lines, as the part the subscriber may play in procuring his own service is not very important. In the larger cities where a man has his mind occupied with various details, he is not so anxious to manipulate the instrument himself. As a result, it appears that ultimately the desirable service, or the service the public is going to demand, would be the manual.

In handling the manual service, our present switchboards are designed so that we can place within the reach of one operator 9,600 lines. Of course, on a jack per line basis, this would mean an additional number of stations probably a ratio of 70 lines to each 100 stations, but when you reach the capacity of 9,600 lines, it means additional multiples. It means that you will have to install trunk switchboards that will have additional multiples and are considered second units. The capacity of each unit will be 9,600 lines. That is, an operator answering a call on the first unit must out-trunk same to the second unit.

Now in a city like New York, where they have over 300,000 telephones, it resolves itself to a question of what per cent of the total calls are out-trunked, and it is figured that when approximately 70 or 75 per cent of the calls are out-trunked, it is just as economical to out-trunk 100 per cent, which means all calls originating at the 'A' position will be out-trunked.

Mr. Clement describes a clearing-house system and also operating centers, but I could not quite grasp his idea. It would seem to me that the ultimate solution of this problem would be something like this—to provide a number of operating centers in a city like New York, each located at what we term 'Wire Centers', that is a particular center at which the greatest number of wires radiating from same would be the shortest, when you take down your receiver, your signal would show before the 'A' operator and after giving your call—say for instance Broadway 4519—she would then simply manipulate the keyboard and the rest of the action would be automatic, that is, it would select a trunk, arrive at the other office, select the particular number you wished to talk to and ring same—then you would have solved the operating problem and also the telephone problem as well as it can be solved in our day and time. I am of the firm opinion that the ultimate solution of the problem of handling telephone traffic in the larger cities is the semi-automatic method and that the full automatic will serve the smaller cities.

Mr. Schuler: There is one thing that the gentleman spoke of that interests all of us who are in the telephone business. We are in the telephone business for one thing, and that is to sell service. Now, the point in my mind is this, that the company that is in the telephone business and is going to do the most business is the one that sells the best service. I have in mind a place where the Bell Company had nine hundred subscribers and the Independent started with 250 subscribers four years ago. Now the Independent company has 1,567 subscribers and the Bell Company has less than 200. The one thing that accomplished it was service.

Now, what constitutes service. Service is constituted by a man going to his telephone and getting the number he wants in the quickest possible time and getting the best possible transmission after he gets his number. That is telephone service. If you go to your telephone and try and try to get a number and don't get it, and even after you do get your number you don't get transmission, you are not getting what you pay for, and the man in the telephone business is not delivering what he is paid for doing. In my mind the best proposition for delivering telephone service, I don't care whether it is wireless or with wires, or whether with telephone or without telephone, that will put A in communication with B and give A that communication in the least possible time and give them both the best possible transmission.

I have made a number of tests—I happened to be manager of the first two-wire system put in existence—I made a particular investigation of why we could not get business. The Bell people were not giving service. We were giving service so far as our calling and our transmission were concerned, but we were not giving service because the people did not use the apparatus right. Now, if we had had in that little Illinois town the automatic, or semi-automatic service, I believe we would have gotten the business. I called on 100 of our subscribers and asked each one which they thought best, which they preferred to use, and they preferred to use the manual service, but they admitted they could get better service over our lines, but they did not want to be bothered with the necessary trouble.

I have made a number of other tests in regard to service. I tried getting 100 subscribers on the manual and getting 100 subscribers on the automatic service. The automatic service was a new plant and everything was working right, and I would get my 100 subscribers in a great deal less time, making allowance for the parties who did not answer, the moments lost in waiting for parties who did not answer on one was as much as the other —I would get my automatic subscribers in less than 80 per cent of the time it took on the manual. I visited 100 subscribers and asked them which they preferred to use—whether they preferred to give the operator the number and let the operator call it, or the automatic. A large per cent preferred to give the number to the operator, so I am thoroughly convinced that the semi-automatic is the best equipment.

H. B. Tupper: Mr. Clement in his paper says, " It appears that after the operator has answered the calling subscriber and puts up his connection, she clears out and if the subscriber does not get the called party he has no means of determining whether that subscriber does not answer or whether that line is in trouble, unless he should flash his hook and probably come in on the apparatus again and go through the same sequence as the first time"

We use a method in the manual system, we have toll switching positions, automatic stick down keys, which work the same as those Mr. Clement speaks of. The operator plugs in to the subscriber's calling jack and the ringing is done automatically through a machine ringing segment on the ringing machine. This machine ringing device throws out alternating currents and direct currents at intervals on the operator's line to the subscriber, and it will continue to ring until the subscriber removes his telephone from the hook, which indicates he does not get it and he can get her again and tell her conclusively whether the line is in trouble or whether the subscriber does not answer. That is a point that should be embodied in the automatic—the possibility of the subscriber getting in touch with the operator without going through the sequence of working up his automatic machinery again.

C. L. Cory: I have enjoyed the discussion of the automatic, the manually operated and what has here been called by different names, the half or semi-automatic or automanual telephone systems. Considering the matter somewhat carefully from yesterday, it would seem that we should view the telephone situation fairly and from two entirely different standpoints, one with the attitude of the subscriber or customer, the other as necessarily viewed by telephone engineers who have been engaged for years in perfecting all of the very complex apparatus adopted and so successfully used in telephone systems.

The requirements of the subscriber may be compared to that of the customer requiring illumination, using electric light. Illumination from such a source of light is needed as a substitute during certain hours of each 24-hour day in place of the natural and free illumination available in day time. As long as the sun provides sufficient light the individual only finds it necessary to raise the shade to the window in his room. In the absence of sunlight many years ago man found it necessary to devise a substitute, and perhaps in the order of use, pitch pine, the candle, and the coal oil lamp, all of which sources of light were under the complete control of the individual desiring the service.

Upon the introduction of gas and incandescent lamps the service was not completely under the control of the customer. In somewhat the same way we may consider telephone service.

I myself frankly believe that the method by which one calls or attempts to get in communication with the person with whom a conversation is desired should be considered from the psychological as well as from the engineering standpoint, although of course the methods that may be employed by the customer and devised by the telephone engineer are engineering problems, but it will not do to lose sight of the attitude of mind of the subscriber in coming to a definite conclusion as to the best system which may be employed.

Those requiring the use of electric light had nothing to do with the change from the carbon to the tungsten incandescent lamp. Yet the service is much better and cheaper with the latter than with the former. Viewed exclusively from the standpoint of the customer, he might have been thoroughly satisfied for all time with the old carbon lamp, but nevertheless the customer is pleased and gratified as a result of the introduction of the tungsten lamp as a substitute for what was previously considered entirely satisfactory, namely, the carbon filament lamp. The illustration may be crude, but it may serve as evidence that the character of service planned for the customer by the inventor may not be the most desirable to the individual paying for the service.

Again suppose it is my desire to speak to Mr. Miller. As we are now both in this room I merely address him. The entire conversation is within our control; barring some noise or similar interference from the outside our mutual understanding of one another can not be prevented. Mr. Miller hears me addressing him and replies directly. Nobody can interrupt our conversation. In a way such a conversation may be likened to sunlight as a source of illumination. It is free. It is controlled as we choose and no interference is possible from others.

When artificial illuminants were introduced without question the idea was in so far as possible to get results approximating the illumination of the sunlight, not free of course, as this would be impossible. Similarly I can not talk with Mr. Miller when he is in Pasadena as I do here, nor can I talk with him when in San Francisco. We need some artificial arrangement, which is the telephone, in order to make our conversation possible at the greater distance. Notwithstanding this, my attitude of mind as I desire to talk with Mr. Miller when he is distant certainly approximates the condition which we can so readily establish here when we are within a few feet of one another. This obvious fact will certainly be admitted by all. It is the work of the telephone engineer to approximate that condition.

To put it in a little different way, Mr. Miller may be across the street, or in Pasadena, or Long Beach or Redondo or San Francisco, and I desire to talk with him. No matter where he may be it is my desire if possible to carry on a conversation with him as I may do here in this room. This is the attitude of every telephone subscriber. In order, however, to get into communication with Mr. Miller, what is my preference. Spell out his location myself, because that is what it amounts to in the automatic system, or remembering that I am subject to error, would I prefer to take the telephone off the hook, addressing an operator in the central office and trust to the system, which includes operators and devices, to connect me with him, no matter where he may be. I have been impressed greatly and much admire the mechanisms that have been evolved in the automatic system, but the question finally comes down to this: would I prefer to simply express my desire to talk with Mr. Miller by giving his number to the central, or individually spell out Mr. Miller's location myself so that I may talk with him.

The preference of the subscriber in such an instance, it seems to me, depends entirely upon conditions. It may be necessary and really demanded that the automatic system be used, by which every individual, no matter what language he may speak, finds it possible to spell out the location of the person to whom he desires to talk, as was stated here might happen in Havana, or any other city containing in its population subscribers speaking many different languages who use the telephone, but it does not necessarily follow that this is desirable in a city using say 300,000 telephones and covering an area less than the city of Los Angeles.

Naturally the telephone engineer has confronting him the problem of providing as far as possible a system so that I may talk to Mr. Miller if he is in Los Angeles, only across the street, or in San Bernardino or San Francisco in a manner as nearly as may be as we talk together in this room. As a matter of fact, I may not know in the beginning where Mr. Miller is, and it does seem that the plan where we have combined local and long distance service, whereby a skilled operator is used in locating the person to whom one desires to talk, may perhaps be much better than to have such locating done by the customer, who can not possibly be so skilled as a regular operator.

If the automanual as has been described in one of the papers here will make it possible for the subscriber to call up central, give the number desired, and then the operator in the central office by using a similar automatic device can the more accurately, speedily and economically connect the subscriber with the individual called, that system it would seem would be the best of the three under discussion as treated in the papers presented.

In conclusion it should be said, I think, that the problem of devising the best possible telephone system should be viewed not solely from the standpoint of the subscriber, but very largely so. At the same time, all of the possibilities should be given the most careful consideration by the telephone engineer. The requirements of the subscriber should be met as far as possible by the telephone engineer, whether the service required is long distance or local, in a small community with a comparatively small number of telephones, or in a great city of large area with hundreds of thousands of telephones, any two of which may be connected together in the least possible time, and in the operation of which, without question, there will be a decided peak load during certain hours of the working day which must be taken care of if the service provided is satisfactory.

Arthur Bessey Smith: The paper presented by Mr. Clement is very interesting in that it presents clearly a very essential question involved in exchange operation. The question may be stated thus. Is the human element necessary and desirable in connecting exchange lines? While every human activity requires human attention to some degree, there are many things which, on account of their nature, may be better and more satisfactorily handled by machinery. Before we can decide whether or not the telephone exchange comes within the automatic field, it is necessary to consider two features, *viz.*, the nature of telephone service and the practicability of selecting lines by automatic machinery. Since Mr. Clement has himself acknowledged the latter point, we may confine our attention to the former.

Telephone service consists essentially in establishing means whereby conversation may be held between two points. This is usually limited to speech transmission by electrical apparatus connected by wires. When we have turned such an arrangement over to two or more people to use, we have rendered telephone service. Since the outfit is usually owned and maintained by a company for public use, a fee is charged whenever it is loaned to any person or institutions. Also because the people must pay for telephone service it demands that the service shall have some degree of quality.

The elements of quality in telephone service are, in order of importance, as follows:

Accuracy of connection, quality of transmission, speed of connection and disconnection, proper treatment and ease of securing connection.

Voice transmission is usually very good in modern exchanges so that for our present discussion we may omit it from the list. This leaves the following:

1. Accuracy of connection.
2. Speed of connection and disconnection.
3. Proper treatment.
4. Ease of securing connection.

Theoretically, it might seem that the human element is indispensable to the rendition of good service, but practical experience has shown that almost all of an operator's work is inherently mechanical, requiring no judgment. In the total of a day's work, the calls which require intellect are so few that they can be cared for by very few clerks.

The automatic switchboard can render excellent service in all of the elements named above. These I will discuss in detail.

The transmission of a number by mechanical and electrical means is far more accurate than by voice. In the messenger company analogy, used by Mr. Clement, the public would not entrust its business to such a concern if address of a parcel were given to the messenger orally .Nothing but a plainly written address will do. There are many chances of mistake in oral transmission, both on the part of subscriber and of operator. The act of spelling out a number with a calling device is naturally conducive to accuracy since it is done through sight and touch, the two senses upon which man places his greatest reliance.

From the standpoint of the subscriber, automatic service is quicker than either manual or auto-manual. The time from the initiation of a call to its connection through the apparatus is from a third to a half as long with automatic as with auto-manual. The saving when compared with manual service is even greater.

It may seem strange to compare a human operator and a switch as to " treatment of the public," but the relation exists and is very real. Far from being " the principal ground for confidence " the operator touches the public with a treatment as variable as her moods. The automatic switch treats the public with uniform courtesy—the courtesy of implicit obedience. In all but a limited number of cases no subscriber asks more than that his desire for a connection shall be quickly and accurately made, which service the switch certainly performed. The automatic switch accords the public the best possible treatment.

Generally speaking, to relieve the subscriber of all work possible is not necessarily inconsistent with the highest type of service. The highest and best service is rendered when we most completely meet the subscriber's desires and needs. Further, not all the labor of making a manual call is felt by the hand, for the brain and the organs of speech are involved. Compared with the oral transmission of a number, it is a relief to turn the dial. The subscriber does not feel it to be a burden, but regards it as an efficient means to an end. He asks for *results*.

To sum it up, I believe that the amount of telephone traffic which requires direct access to human intelligence is so small as to be negligible. The small class of calls which requires special attention should be handled as at present by clerks, who are not operators. For the great bulk of traffic the human operator is not only unnecessary, but a positive hindrance to good service. People desire *service*, that is, telephonic connection, which the automatic switch has the special capacity to give. The perfect rendition of this service has established among automatic users a feeling of strong confidence.

Henry P. Clausen: Mr. Clement states that in the manual switchboard an operator can attend to from 280 to 290 connections per hour. While I do not think that this figure is any too high, the records of the average exchanges throughout the country will run more closely to the 250 calls per hour figure, and that only during the busy ten hours of the day. During the peak hour, however, operators will frequently go as high as 400 calls per hour, and for short periods an observation has shown that an operator can answer as many as 425 calls per hour. 300 to 330 calls during the peak load is not at all unusual. In fact, in one of the exchanges mentioned by Mr. Clement the writer has found a record showing 288 calls per operator's hour, and it is interesting to observe that 63 operators on duty at the same time were averaging this number of calls.

According to Mr. Clement's statement, only 31 per cent of the total cord circuits are in use at one time during the peak load. The writer does not think that this can be absolutely correct, and, in fact, upon consulting the records of one of the exchanges cited, 63 positions were in service, each equipped with 15 cord circuits, and out of a total of 18,200 calls during the peak load, allowing three minutes per conversation, 96 per cent of the connective means were in service; and, taking the run of calls during this particular day, out of a total of 189,000 possible three-minute conversational connections, 135,000 calls were taken care of, which then gives us about 70 per cent of the connective means in service during a continuous run of ten hours..

Another statement made by Mr. Clement refers to the expense of operating the trunk circuits in a certain exchange, which, he says, amounted to 31 per cent of the total operating charge. As Mr. Clement gave the name of the exchange, the writer was in position to examine into the records and found the following: Out of a total of 21,300 calls, requiring 198 operators' hours for handling them, 6500 were trunked outward, which equalled about 30 per cent. The incoming trunks amounted to something over 5600 calls during the day, and these were taken care of by 58 B operators' hours. Mr. Clement probably had the above records before him when preparing his statement, and therefore did not carefully consider the local conditions, for, when it is learned that in this particular exchange the B operators, instead of answering calls of from 350 to 400 per hour, as is the usual practice, were only answering 98 calls per hour, it will reveal to every traffic man a serious condition of affairs, requiring correction.

In discussing full automatic exchange operation, Mr. Clement suggests that irresponsible persons may call anyone and cause a great deal of annoyance without danger of detection, and, as I understand the description of the automanual system, the same difficulty remains, for, when an automanual operator sets up a connection and presses the starting button, this connection passes beyond her control and she is not able to detect any improper use of the telephone.

I believe that it is admitted that in the full automatic exchange one attendant is required for every 700 subscribers, these attendants taking care of the automatic switches, supervising them while the exchange is in operation; but it is not brought out by Mr. Clement that the automanual system, employing, as I understand it, the same number of line switches and trunking switches as the full automatic, must also employ the same number of attendants. This would very seriously increase the operating expenses.

As to the statement that one day's training is sufficient for an automanual operator, this may require some qualification in the direction of understanding how efficient such an operator may be for performing the difficult feat of handling subscribers calling for service.

It is further stated that all operations in the automanual system are standard. How are the different classes of service taken care of; for example, pay-station, measured service and flat rate service. Such calls as require the recording of subscribers' numbers should prove very difficult in the automanual system, for the operator has nothing before her to indicate the calling subscriber's identity, and it would appear difficult to obtain it other than by inquiry, and then at the risk of being given the wrong line number or wrong information. At any rate, pay-station and measured service calls, which in many exchanges run into quite a large percentage of the total number of subscribers' calls, cannot be handled at the high rate claimed in Mr. Clement's system.

In the comparative work units submitted, and based upon the number of movements of the A operator in handling a local call, a more equitable division could have been made, but Mr. Clement makes the serious error of completely ignoring the presence in the manual switchboard of overlapping operations upon the part of an operator. Each distinct operation is said to be performed to the exclusion of any other; this, while it is true for the automanual system, is not the experience in manual operation, for in the manual switchboard an operator can respond and does act upon audible and visual signals practically simultaneously, and at the same time each hand may be used for a different operation. As a matter of fact, it would be impossible for an operator of a manual switchboard to handle 300 connections per hour were the overlapping not present, for telephone calls do not always accommodatingly originate in equally timed periods as they should if each operation were distinct and separate from every other operation, for at times three, four, or more calls appear upon a position at practically the same instant and a great many of the answering operations are then performed practically simultaneously.

It is at this point that I want to bring out one of Mr. Clement's suggestions, " When a subscriber calls, if he receives a quick response, he is satisfied, even though a slight delay occurs later," for it is the overlapping operations which permit the operator of the manual switchboard to produce what we call a three-second's service. An operator cannot possibly complete, say, four calls in their entirety in three seconds' time, but she can answer the calls in that time by quickly inserting the answering plug into the jack and calling for number.

In the automanual system, as understood by me, an operator is expected to answer 1,000 calls per hour, which in an exchange originating 5,000 calls during a busy hour means five operators. What is the result when—as it is entirely probably—20 subscribers' calls are received within a given second or several seconds' time. According to the figures upon which the automanual operation is based, it takes an average of 3.6 seconds for an operator to respond to and set up an automanual connection;

therefore, in order to answer the 20 calls, it will require 72 seconds time; dividing this by the five operators who are not able to perform any overlapping operations, it appears that at least 14 seconds must elapse before the last one of the 20 calling subscribers is disposed of; and with more than 20 calls the delay would be much greater. This, I believe, is one of the most important points not discussed by Mr. Clement.

C. S. Winston: Mr. Griswold brought up the question of the method of handling reverting calls in an automatic system. Most of you probably know that a reverting call is a call from one station on a party line for a second station upon that same line. In manual equipment this does not present any very difficult problems, but in the automatic it is a very different thing. In the three-wire automatic the problem has been solved and it is possible for one party to call for another on the same line without knowing that he is calling for a station upon the line upon which his station is located. In the two-wire automatic, using automatic ringing the problem is entirely different. Up to the present time, I believe, no satisfactory means has been found for accomplishing this result, and hence it is necessary for a subscriber to know that the telephone of the man with whom he wishes to talk is upon his own line. If he does not, he will call and receive a busy test just the same as if he were calling for a separate line which was in use. The number of calls, however, of this sort, I understand, is not very great, and I do not think that any particular trouble has been experienced with that difficulty.

No telephone system is or ever will be absolutely without defects, or entirely ideal. This refers to manual equipment as well as automatic equipment. In the automatic system, if a subscriber upon a party line takes off his receiver at the time the second subscriber upon that same line is signalling, trouble is sure to be met as the impulses which are sent subsequent to the removal of the second receiver will be lost and the proper station will not be called and possibly no station will be signalled. I see no way in which this defect can be overcome. It is one of the defects which seemingly are inherent in automatic equipment.

In automatic equipment difficulty is met in the handling of measured service. This is true either when service meters are used at the central office, or nickel boxes at the subscribers' stations. That is, if a party is called and another party responds the charge is made just the same as when the call is properly completed.

Mr. Griswold also brought out another point in regard to two subscribers plugging into jacks of the same line simultaneously in the system which I referred to as the automatic distributing system. I don't think that trouble will be met with on this account. In the system which my company has laid out, more or less in detail, there is a relay in the cord or trunk circuit which operates as soon as the plug is inserted into the jack of a line and if two plugs are inserted into two jacks of a line simultaneously, it would be necessary for them to operate at the same instant before trouble could result. I don't think the chances for this to happen would be as great as the chances in the manual system of missing the busy test and plugging into the jacks of a line already in use.

It was suggested by Mr. Miller, I believe, that a possible solution of the problem might be in the combination of the semi-automatic and the full automatic. It hardly seems to me that this would be a satisfactory arrangement. In communities where the plan has been used of operating both common battery and magneto telephones the results obtained, I understand, are very unsatisfactory. If a man has one type of telephone and a friend of his one of the other type, he is apt to make up his mind that he prefers the telephone which John Jones has and he is not satisfied until he gets it. It seems to me that trouble would be met with if this suggestion of Mr. Miller's were followed.

Such an arrangement would complicate the central office equipment, require extra apparatus equipment and hence the expense of maintenance would be increased. I don't think the service would be as satisfactory as if either one of the two systems were used alone.

It has occurred to me that there may be confusion due to the fact that in my paper I referred to the " semi-automatic system " and Mr. Clement referred to a system, practically the same, as the " automanual system." There are no differences as far as operation goes and the differences which exist are all merely differences of detail. The automanual, or semi-automatic, is nothing more nor less than an automatic system in which the dials are removed from the subscribers' stations and operators at the central office do the work which is done by the subscribers in a full automatic system.

Very frequently in semi-automatic, or automanual there is more or less trouble due to the fact that after the connection has been established, as Mr. Clement has already stated, the operator is entirely disconnected from the circuit. If for any reason the subscriber desires, after the connection has been established, to call the attention of the operator, or perhaps I should say to converse with the operator, the operation of the switch-hook will disconnect the apparatus entirely and instead of calling the attention of the operator he called originally, he may get some other operator. This may cause trouble, although I understand not a great amount has been experienced in the three or four places in which the automanual is now in use.

It does not seem to me that automatic equipment is likely to be used in small towns. I don't think there is likely to be any great conflict of opinion in regard to this point. In small plants the cost of maintenance must necessarily be low and the original cost of automatic equipment, and the cost of maintenance, would in all probability make it prohibitive.

Mr. Clement stated in his paper that in a telephone system subscribers pay for service and hence should not be bothered with duties which should really be done by the operator. I hardly agree with him in this respect. I seems to me that if the subscribers do not object to performing this work, and advantage is gained by using full automatic, it is certainly justifiable to do so.

This brings us up to another point. One or two of those who took part in the discussion have stated that they thought this whole subject would result in the adoption of the system which would give the best service. While, of course, service will play an important part, yet I think it is a secondary consideration. The foundation of any business is laid upon the returns which are expected from the investment; that is, you get down to the old proposition of the almighty dollar. If it is found that automatic equipment can be bought and operated at less expense, and hence will give greater returns on the investment than manual, it is the system which will be used.

In places in which automatic has been employed, the subscribers have shown that they are willing to operate the dials without complaint and it seems to me that the operating companies must decide which system will meet their ends best, and install that equipment universally. The service, of course, will be improved, and kept at as high an efficiency as possible; but it all boils down to the fact that it will not be improved unless an improvement will increase the returns upon the investment.

E. E. Clement: The work which I present is individual work, and I have tried to present it in an individual way. I have tried to look at both sides of this subject impartially, and having gone into the question very thoroughly on both sides, I long ago personally decided in my own mind that the semi-automatic principle, in whatever form embodied, would necessarily be used in the future. Of course I have advocated that ever since. Now, a man ought to be able to give some reasons for the faith that is in him, and that is what I have tried to do in my paper, and shall continue in these remarks.

Mr. Keller read a very interesting letter from a friend of his in the Siemens and Halske Company in Berlin, in regard to their work over there. I would not refer to this except that Mr. Keller in discussing it stated that he had been surprised to learn that the Germans had been developing along my line. Dr. Raps and Mr. Grabe, of the Siemens and Halske Company, have been in touch with me. They were over here several years ago with a party, and were given every opportunity to see my work. They are desirous of introducing these improvements in Germany, and I mention this so that no false impressions will arise as to the situation. I do not believe that the Germans or any other foreigners have done any substantial work in developing the automatic or semi-automatic systems in any form in which they appear in this country.

Mr. Keller also referred to changing what he called "half-automatic" to full automatic, and to "mixed" systems. I tried to make clear yesterday and in my paper that in my automanual system there is one vitally distinctive feature, (among a great many original features) which is not found in any full automatic system, or in any of the ordinary so-called "semi-automatic" systems, of the type referred to by Mr. Winston. I refer to the use of an operator's trunk, separate and distinct from the talking trunks which are used to connect the subscribers for conversation. Disregarding this, the basic principle of semi-automatic amounts to no more than moving your senders in from the subscribers' stations to the central office. There is no reason, either technical or psychological, why a mixed system should not be employed if it is wanted; that is, we can arrange our circuits so that all the connections are made by automatic switches, but some of the subscribers can have senders and work the switches direct, while the rest of the subscribers are handled by the operators. This condition would actually exist during the process of changing over an existing full automatic equipment to automanual, which we can do very readily, but for permanent use I would not care to recommend such a system.

In considering my individual operator's trunk, it must be remembered that any semi-automatic system which ties the operator to the talking trunks necessarily loses almost all the advantages of operator-centralization. The key to the solution of this problem is in the provision of separate operators' trunks, which are automatically connected to and disconnected from the talking trunks, and which can be made of any length desired, so that the operators can be centralized or shifted around, or divided into different centers, or otherwise handled as traffic conditions and the discipline of the operating companies may render desirable. This, with a number of other features, are broadly new and peculiar to my automanual system. I know quite a number of these features have been taken up and followed by others as we have developed and announced them. I am aware that other people will try to get into this line of business, but these are commercial questions with which the Institute is not concerned, and I am sorry that others have brought them up. At the same time, I am glad of this opportunity for an answer on my part. I may say that I believe, commercial and legal questions being disregarded, if every telephone manufacturing company started making similar apparatus, the supply would not exceed the demand in the next ten or fifteen years.

In this same connection, the matter of making a recall has several times been referred to. It is stated that if the calling subscriber gets his connection and the operator is cut off, the subscriber cannot call her back. This is true, and no trouble can or does flow from it, the facts being quite contrary to Mr. Winston's statement this morning. In my system the subscriber hangs up his receiver, is instantly cleared out, takes down his receiver and instantly gets an operator, who may be the same or another. The whole operation of hanging up and taking down is practically instantaneous, much quicker in fact than any ordinary recall could be. What is the use of tying the operator up and interferring with the work. If a man wants to make a recall, he can do it better by making a fresh call. If he wants to report some trouble, or to make another call, he can get the operator or he can get the trouble clerk, without delay.

Reference has been made in the discussion to the full automatic system operated through subscribers' metallic lines without grounds. As I have stated, I can operate my central office mechanism from the subscribers' stations, over metallic circuits, and in fact I may state broadly that I can do with this system anything that is done or could be done with any full automatic, for the obvious reason that I have the full automatic equipment at the central office; and I can also do anything with this system that can or should be done in a manual system, for the obvious reason that I have operators at the central office, while the subscribers' equipments and line connections are the same as in the manual system. In fact, when I started, a good many years ago, to attack these problems, I first of all worked out those which are common to all automatic practice, among them the metallic circuit problem, which seemed very difficult in the beginning. Years ago I was able to make a report with blue prints of two wire metallic circuits which had been then successfully working automatic switches for a long time, using timing solenoids instead of the magnets referred to by Mr. Winston. In that full automatic circuit I also had selective automatic ringing, which has been successfully working ever since, having been grafted into the automanual circuits. I believe the principles thus discovered are indispensable for good practice.

Mr. Griswold, and some of the other speakers, on the question of reliability, have referred to the question from the subscribers' standpoint alone. I think we must look at this problem from every standpoint, not only the subscriber's but the company's, and also as Professor Cory has said, the standpoint of those engineers and their associates who have given their lives to developing these systems. In the practical aspect of the question, there are only the subscriber, who wants service, and the company, which is called on to furnish that service in enormous quantities, and must therefore practice economy as a matter of absolute necessity. Economy however, must be effected without detriment to the service given the subscriber.

I have devoted a good deal of time, in conjunction with Mr. Boylan, to collecting and comparing traffic statistics. If you will read the first ten and the last ten pages of my paper, which are devoted largely to discussion and tabulation of this traffic data, it will save me from going into a lengthy explanation now. In regard to some of my diagrams, particularly Figs. 17 and 19, you will observe that I have shown only two curves for comparison, one the manual curve showing cost of operating, and the other my automanual curve. I did not attempt to plot a curve showing similar costs in a full automatic system, because of a desire to be extremely impartial, preferring to present the figures, as I have in the argument, and leave the comparison to you. My reason for this was primarily that in the full automatic system, you cannot entirely segregate the operating expense from the maintenance and other costs. Now, how the various operating companies employing full automatic systems, keep their accounts, I do not know in detail. I have seen some of their reports and some of the data used in making up their statements, and they are very interesting; but I would not plot a curve without compiling and comparing these to an extent that has not been within my power in the time allowed for preparation of this paper. However, I believe, and I think you will agree with me after reading the figures I have given, that if the automatic cost curve were plotted in Figs. 17 and 19, it would lie between the manual and the automanual curves which I have plotted. I have stated in the paper that the net saving per annum in mere operating expense as such, by the use of full automatic equipment, cannot be more than 50 per cent of the manual operating expense in a system of any size, and that it is probably very much less. This may or may not agree with the facts in all cases. That is for you people to determine. You have better statistics at your disposal than I have. I show a saving however by the automanual over the manual in one given case of 77 per cent (see Fig. 17), and I also show an extreme case which I may state is based on studies in the city of Cleveland, Ohio, of the traffic of both companies which are competing there, in which the use of the automanual system will save 86 per cent of the present manual operating expense. As opposed to this, if the two companies were to trunk direct between their switchboard by manual methods, it would increase their present separate operating expenses by an average of 40 per cent, which makes a total difference in my favor, operating under the same conditions, of 120 per cent of the present total operating expense. The question for you automatic men to determine is, what will you be able to do with your equipment when you meet a similar condition.

Traffic conditions in the telephone business at present are fairly comparable with those in the railroad business. This country has been growing with most tremendous leaps and bounds, and we have not yet reached anywhere near the limit. When you have only a few instruments to handle, it is easy to consider only reliability, and forget the cost of service. But when you are dealing with a city exchange handling from six hundred thousand up to several million calls per day, and those calls cost anywhere from $1.50 up, per thousand (the Cleveland combined figure is $1.96) then it becomes indeed a serious question, and you cannot yield to the subscriber entirely. With the automanual handling these calls at 25 cents per thousand, however, the subscriber should get all the attention he needs. This system is designed to give the subscriber the same grade of service that he gets in the best manual system, that is the individual attention of the operator, and the benefit of her training with all the other benefits flowing therefrom, but at a minimum cost to the company.

One question asked is was what happens if a line is called and the subscriber does not answer, the operator being then off the connection. For this condition I provide a special tone test signal, which comes on if desired after a certain number of rings, or we can handle it through a monitor, or in any other manner possible in the automatic. I preferably provide signals for every condition, which I find the subscribers learn to distinguish very readily. At Ashtabula, we have a busy-back, substantially the same in its functions as that with which you are familiar in your automatic systems. We also have a don't answer signal, but the calling subscriber preferably hears the ringing. We also have a special tone test for the case where the calling subscriber hangs up before the operator gets to him, which she hears when she listens in. We also have an indicating board, with lamp banks, and other signals, so that any condition of trouble or line in trouble can be traced by the wire chief. We also have the other expedients for various purposes with which you gentlemen are all familiar in your practice. Our circuits are very full and complete as to details, and a great many of these are novel, but time forbids my going into them.

With respect to reverting calls, I have no trouble with those. The condition which must be produced when you go to test your own line, which ordinarily would then test busy, is almost obvious. You must produce a neutral condition at the instant of your own test. This has been done in several ways, and we have done it in practice by having the last impulse from the sending machine which works the test relay, also sent back at the same instant to the calling end to reverse the test potential. This applies to a two-wire circuit as well as a three-wire. We test on the tip side usually, and have no trouble at all. I am surprised that Mr. Winston made the statement he did on this point, but presume his information was defective.

I agree with Mr. Winston that the percentage of reverting calls is so small that it hardly pays to take care of it. I took this up with a number of the managers of the larger companies in the east, to see what experience they had; and while there are special test signals available for reverting calls, as you may know, in the old manual practice, these people didn't consider the number of such calls sufficient to make any regular provision for them. The way we take care of them at Ashtabula Harbor is this: There is a master switch at the back of a key set, so the operator getting a call for another party on the same line, can cut on a special first selector and disable the associated secondary selector, so that no other calls can come in on her key set for the time. She then handles that call in the ordinary way. The caller gets his party and then the selector switch is knocked down, leaving only the connector on the line. All it needs is ringing and a battery supply. The battery supply, through one bridge connection in the connector, only, is a little less than normal where you get feed both ways, but, on the other hand, you don't need quite as much, because you are talking through a short circuit. In order to ring past the calling party, you have to tell him to hang up.

You will observe from the tables I give in my paper, that this does not affect the operator's efficiency. The percentage of such calls is very small, although we have quite a party line development in Ashtabula.

Mr. Foster referred to complaints against the operator. I tried at first to eliminate all sounds and all disturbance from the calling circuit after the operator had gotten the number, that is, to prevent the calling subscriber from hearing any of the actuating impulses or ringing, or anything else. We found, however, that silence was a bad feature. A man gets the operator, he gives her the number, and he has no means after that, if there is dead silence, of knowing whether she is doing anything or attending to the line, and if, through mischance, he does not get his connection, there is complaint. We have now arranged our circuits so that a subscriber, after the operator gets the number and starts the impulses, hears those impulses faintly, and he can also hear the ringing. He also knows that the operator is not on the circuit after she has made the connection, and that the ringing is automatic, so that if there is any blame, he attaches it to the other fellow for not answering.

Now, with regard to the condition of strained nerves on the part of the operator, and that sort of thing, in the paper I have taken occasion to show that in this keyboard arrangement by confining the operators simply to asking the number, we relieve them of a very large part of the purely manual strain; that is, we take the actual work to be performed off them and put it on the machines. The work on our keyboards is very light. The touch is more delicate than the touch of a typewriter or adding machine. We have made it as light as is consistent with reliable operation. So we don't have a condition of strain on the operators, and no one operator is any busier than another. Their work is very light, and if there is any complaint coming or any discourtesy or anything of that sort, the operator does not bother with it for one second—she simply pushes two keys, this puts the party on to the trouble clerk, or some one else, and she is through with it. Our operators are confined to just one thing—asking numbers and setting them up; and to that extent they are mechanical; but they have brains, and if there is an incoherent number given or any trouble, their brains get busy. They don't get any complaints and they don't need them.

The question was asked what happens if a cable goes bad or some other condition arises that might affect a whole group of the apparatus. We have special provision for that the same as in the manual or the automatic. We have the same resources so that we can switch off a whole group of lines and put them on to the wire chief or in the hospital or somewhere else, if desired.

In regard to favoritism on the part of the operators, the P. B. X. operators being accessible by means of candy and so on, if not properly fixed giving poor service—there is another feature in the automanual system which I consider of some importance; that is, that the operator does not know who is calling. Reference was made in the discussion of one of the papers to the primary and secondary distribution in Mr. Keith's system; that is, the automatic electric. I have a primary and secondary distribution apart from that of the operators, by which practically any trunk in a very large group can be reached, and it can be arranged so that any subscriber may reach any operator in the whole exchange. That makes it practically impossible for any operator to know who is calling, unless she has a very remarkable memory and the transmitters are very uniform, or the man tells her, and then she is running the risk of the supervisors reporting her. That eliminates the question of favoritism entirely.

With regard to foreign subscribers, it happens that we have had some experience with them. We have quite a foreign population at Ashtabula Harbor, and I don't think we have had one complaint from those people as to the operators not understanding their numbers. This may result from the fact that some of the operators in the exchange—not all of them—were drawn from the native population. I presume they are accustomed to the linguistic idiosyncrasies of the people. In the case of Swedes, select a Swedish operator for them, the same as you have Chinese operators in San Francisco. Before spending forty or fifty thousand dollars extra for apparatus to accommodate these subscribers, better invest in a little foreign assistance.

Another question raised relates to possible defective ringing in case the calling subscriber does not give the number of his party on the line wanted. It is possible to group the lines so that all party lines are segregated; and then if a calling subscriber fails to give the letter or number, the operator can ask him. She repeats the number back as she sets up the keys, and the subscriber would then probably repeat the ringing letter even if she did not ask. Where all the lines in an exchange are party lines, the question would always be asked.

As to the methods of compiling our data: I have a photograph of the Horograph, so-called, made for automobile timing. It is a very interesting machine, and I will be glad to show it after the meeting. It is guaranteed to be accurate to one one-hundredth of a second. All our reports have been based on this and on automatic peg counts. We have an arrangement of the relays so our peg count is taken every day and all the time, and is absolutely accurate. All the calls are recorded, together with the manner and efficiency with which they are handled.

Mr. Babcock stated that introducing the operator was introducing a weak link. I think that point has been answered by some one else, but I am not going to let it pass, because it is, I think, an error. The answer is this: If, as Mr. Babcock stated, and as we know to be the fact in manual systems as well as automatic, a considerable percentage of the troubles reported is due to the subscribers calling, then where can the weak link come in from introducing a skilled and trained and habitually poised operator in the place of the subscriber? I have covered that subject pretty fairly in the paper, and I don't think I will go any further into it, because I have not the time.

As regards the private branch exchange, practically every line is a private branch line. If you subdivide your system they all get the same service, and they all get personal attention, and at the same time you can have if you want private branch exchange operators. I do not think it is as economical or as good practice to divide the group of operators if it can be avoided. Nevertheless, special conditions will sometimes arise. I know in New York we figured on some parts of the city, for instance, in the brokerage district, where the men are too busy to stop for anything. They want to make a string of calls each day at a certain time, and an operator who can give attention to that is absolutely essential. There it pays to put in automatic branch exchanges. One operator handling these exchanges ought to do the work of about three the way they go now, even with the varied calls that would be made on her.

Finally, as to measured service: I can provide special operators, and segregate measured service lines and other different classes of traffic so as to bring them in to these operators; but I prefer not to, sticking always to the basic principle of confining the subscriber's operator to asking the number and setting it up. We only need to loop any class of trunks through a monitor's desk and the monitor then takes care of the special condition. A special operator who can take those things off a regular A operator is an economy, because not doing anything else she becomes very expert at this irregular duty—almost as expert as the A operator herself. In other words, you have an organization of specialists instead of one person trying to do a dozen things. Of course pay-station calls are handled in the same way.

We have also a system of metering specially applicable to this connective system. I refer to the Telechronometer. This is not the time or place for me to go fully into that, but I will state very briefly that in line with my theories on handling the traffic I also have some very definite theories on the subject of measuring that traffic. I do not believe, and I never have believed that the counting of calls, whether they were charged up as answered or not answered, is fair, either to the subscriber or the company. I do not believe, and I do not suppose any of you who are in the operating end will disagree with me, that a flat rate service is any more fair to the company than it was in the days when the lighting companies used to give so many lights for so much a month. If a man chose to burn them 24 hours a day, of course the company was out. In some cases a flat rate promotes increased use of the telephone and an increase in the number of subscribers, but this is a temporary resort only. The Chesapeake & Potomac Company in Washington, for a time followed a policy of inviting people to use the residence phones frequently, and even to ask the neighbors in to use them. Of course the purpose was obvious, and I think it has been satisfactorily fulfilled. But I prefer to measure the service; and I think we do it satisfactorily. It is measured in units called telecrons. A telecron is a unit of time-distance, and I firmly believe that is the logical way to measure telephone service—plus a base charge which should cover the cost of that much of the operator's time and depreciation on the apparatus, and so on, which is chargeable to the mere answering of the call if the called subscriber does not reply. With an apparatus of this kind, the effect is that at the end of the month the meter shows the total service which has been given during the month in telecron units. If a man has talked three minutes over a circuit one mile long, he has three units charged against him—I am speaking roughly. If he has talked ten minutes over a circuit five miles long, he has fifty units against him, and the toll service and everything else can be metered so as to show the total service. We have an instrument which will give the number of calls also if you want to know that. The distance-rate is adjusted by the operator, who may be the subscriber's operator or a special operator, at the time the connection is made, so as to correspond with the character and length of the circuits employed. The time element is controlled by an apparatus which is running all the time at the central office.

Mr. Clausen appears to be the only one who questions the figures given in my paper. These figures were prepared, and all of my generalizations were drawn, with the utmost care. The following explanations, numbered to correspond with marked paragraphs in the Clausen communication, will substantiate this statement.

1. Mr. Clausen lost sight of the fact that the 280 to 290 hourly connections were specified by me as busy hour non-trunked calls. He makes the statement that the average exchange throughout the country shows a record of 250 calls for the ten busy hours of the day. A general statement of this kind without reference to the variation in percentage of outgoing trunked calls is unsafe to say the least. It may be well to mention that while an operator can handle 290 non-trunked calls, she can only handle 200 calls where the percentage of trunking is ninety.

Mr. Clausen remarks also that operators frequently handle 400 and in some cases as high as 425 calls per hour at the peak of the load. As Mr. Clausen does not specify we must assume that they are non-trunked calls. Neither Mr. Boylan nor I have ever seen or heard of an " A " manual operator handling anywhere near this load. It requires no traffic experience for one to pass on this statement as being beyond bounds. Even were we to assume that the subscribers were not required to give a prefix or affix with numbers on all calls, the number of hourly calls mentioned would still be excessive.

The average calls per operator busy hour in the exchange referred to by Mr. Clausen is 262 and not 288 as stated. The number of calls during the busy hour is one eleventh of the total daily calls. Mr. Clausen evidently estimated a lower figure than this.

2. This statement is incorrect in four particulars. First, the busy-hour load is not 18,200 calls but 16,500 calls; second, the 16,500 calls do not represent completed connections but from this figure must be deducted the " busy " calls, calls for the time, etc., which, conservatively, amount to 12 per cent of the busy-hour calls; third, the average conversational connection is not three minute in this case, and inquiry fails to show such an average in any exchange in the country having 7,000 lines or over). The average subscribers conversation in the exchange in question is 98 seconds; fourth and finally, the average length of conversation during the busy-hour is 25 per cent less than the average for 24 hours due to a greater part of the conversation being of a business nature.

The claim we make is that not more than 33⅓ per cent of the cords on a switchboard are in simultaneous use during the peak of the load. The exchange referred to has 63 positions with 15 pairs of cords per position, making a total of 945 pair of cords, 33⅓ per cent of which would be 315 pair of cords.

There are 16,500 calls handled during the busy hour. It has been stated that 12 per cent of these calls represented busy calls, etc., but to be conservative we will cut this figure to 7 per cent leaving a total of 15,345 possible completed connections.

The average cord time is 98 seconds, less 25 per cent during busy hour or 73.5 seconds, which figure represents 49 connections per cord pair per busy hour, multiplied by 315 pairs of cords (33⅓ per cent of total) equals 15,435 calls, or 90 ***more connections than are actually handled during*** the busy hour.

3. Mr. Clausen raises the point that only 98 calls per " B " operator-hour were handled in the west office of The Kansas City Home Telephone Company, instead of from 350 to 400 per hour which he states is the usual practice. Mr. Clausen is confusing the calls per " B " operator hours with the call per " B " busy hour.

There are several factors, however, which preclude the handling of 350 to 400 calls per " B " busy hour in an office such as that in question, the leading factor being the absence of apparatus at the " B " position which should enable the operator to handle such a number of calls. It is true the " B " operator could handle 350 calls if given the " manual selective ringing service;" 400 per busy hour with " machine ringing," and 500 per hour by utilizing " keyless trunks."

Another factor which determines the number of calls the " B " operator can handle is the number of offices connected with her order wire circuit. With the particular type of apparatus in use at the exchange in question the operator could handle 350 calls provided only one office were connected to her call circuit. This figure would be reduced to 300 calls when a second office was added, 260 when a third office was added, etc. Thus the point that only 98 calls per operator hour is answered shows a condition not unusual and which will be found in any branch exchange connected by order wire to several other exchanges.

4. In compiling the comparative work units we allowed for overlapping operations on the part of the manual operator and the illustration given by Mr. Clausen in which he assumes that 20 calls would land on 5 automanual positions at the same instant can be applied to the manual service. We admit that under a condition of this kind which however, is very far from common, the last subscriber of the 20 would naturally have to wait a little longer than the others. This however is true of any system.

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SOME RECENT DEVELOPMENTS IN RAILWAY TELEPHONY

BY GREGORY BROWN

The standard means of communication on railroads for despatching and blocking trains and transmitting messages for the past 60 years has been the telegraph. Although the telephone obviously possessed some advantages over the telegraph for railroad work, the fact that the railroads had been using the telegraph for such a long period and with such reliable results, made them loath to adopt a new and to them untried arrangement. About four years ago, however, a combination of circumstances arose which strongly focused the minds of railway officials upon the feasibility of the telephone to replace the telegraph for railroad work. The most important circumstance causing this result was the enactment of a federal law limiting the working hours of an operator transmitting or receiving orders affecting train movements, to nine hours. In addition to this, there had been a growing difficulty among the railroad companies in securing a sufficient number of competent operators to take care of the natural increase in business. It was also felt that the efficiency of the railroad telegraph operators had been steadily decreasing for some time, this state of affairs probably being brought about by the attitude of the Telegraphers' Organization toward student operators.

It was estimated that it would be necessary to employ about 15,000 more operators on the railroads throughout the country when the federal nine-hour law went into effect and this large increased expense, together with the difficulty of obtaining good operators, caused the railway officials carefully to investigate the possibilities of the telephone in place of the telegraph, for handling train movements and message work.

Up to this time the use of the telephone by the railroad companies had been somewhat limited. It had, however been in use for a number of years for the transaction at terminals and division points of miscellaneous business between departments and throughout the yards, and also in some cases for the handling of trains in the immediate vicinity of the terminal. In addition to the above, many of the roads have been using the composite telephone in some of their divisions, to assist in the handling of trains and for general railroad business. There have also been two or three instances where the telephone has been in use for a number of years for despatching of trains. As early as 1883 this means of handling traffic was used on the New Orleans and Northeastern Railroad, ordinary magneto telephones being used, together with code ringing. The telephone circuit was about 100 miles in length and consisted of one iron wire, and orders were issued for the handling of four regular trains a day, together with numerous work trains.

The Lake Erie, Alliance & Wheeling Railroad has been operating a line of single track road for a distance of about 100 miles by telephone exclusively for a number of years, with equipment not to be compared with that now available for this service.

The first telephone train wire using improved equipment was installed in October, 1907 by the New York Central between Albany and Fonda, New York, a distance of 40 miles. Shortly after this the Burlington installed a circuit on a double track section and later several circuits on single track divisions. The success attained with these installations conclusively proved that the telephone could be used to advantage for railroad work, and since that time the railroads have been rapidly equipping their divisions with the telephone.

The object of this paper is to outline the requirements to be met in railroad telephone service and to describe briefly the circuits and apparatus developed to meet these requirements.

During the long use of the telegraph by the railroads they have built up an efficient organization for handling trains by this method, and have thoroughly standardized in the method of doing this business. In order to determine the requirements to be met by the telephone, if it is to take the place of the telegraph throughout a railroad division, it will be necessary to examine the methods used and the results obtained by the use of the telegraph.

There are three main classes of service on every division which are performed by the telegraph.

1. Train despatching.
2. Message service.
3. Block wire service.

The train despatching circuit, or train wire, as it is generally termed, extends along one division and is used exclusively by the despatcher located at the division point for issuing orders regarding train movements to, and receiving train reports from, operators along the line. The average length of division is about 130 miles (209 km.), which is divided into a number of sections or blocks, averaging about 20 to 25, there being located at the beginning of each block an operator controlling that block. The length of division and number of operators, however, vary greatly, some divisions being over 250 miles (402 km.) long and having between 50 and 60 operators on the line.

The despatcher has supreme control of each division, in so far as train movements are concerned, and he handles the business somewhat as follows: Each division has its printed schedule of trains, which contains the time of passing all stations and towers, also time and place of meeting for all regular trains, both passenger and freight. In addition to the regularly scheduled trains, there are more or less extra trains to take care of the varying volume of business, and also there are delays which invariably occur, particularly in freight service, due to condition of motive power, time of loading cars, weather, etc.

The above conditions constantly disarrange the schedule and as it is the despatcher's duty to keep traffic moving with the minimum delay, giving preference to the proper classes of trains, such as mail, passenger and perishable freight, it will be readily understood that he is at all times confronted with a complicated problem, the proper handling of which requires great judgment and foresight.

Each of the operators at the block stations has complete control, under the direction of the despatcher, of his block section. It is his duty to report to the despatcher the time of arrival and departure of trains, and also to transmit a large amount of miscellaneous information concerning the cause of train delays, nature and extent of accidents, hot boxes, broken gears, length of time required to repair, track condition and various other items which are factors that the despatcher must take into consideration in planning his train movements.

The bulk of the despatcher's outgoing business consists in giving train orders to one or more of the operators who, in turn, transmit the orders to the proper train crews. A large proportion of the orders are transmitted simultaneously to several operators. The despatcher calls the operators interested and when they are all prepared, he transmits the message, and they each in turn repeat it back, in order that the despatcher may know that his order is properly understood. In addition to the transmission of an order to a group of operators, it will be remembered that the sounders in all the other offices are repeating the same order. This permits every operator on the line, if he so desires, to hear the orders being given and to keep in touch with traffic conditions.

It will easily be seen that it is of the utmost importance that no interruption occur in train wire service, as the despatcher's inability to communicate with the operators would practically result in tying up the traffic of the division. In order to provide for interruptions in service which might occur, due to line troubles, it is customary to loop all the telegraph wires on the line through telegraph peg switchboards located in most of the towers. By this arrangement it is possible, should any portion of the train wire get in trouble, for the operators in the affected district to cut out the defective section of wire and connect in its place a portion of any other telegraph line on the division. This, of course, would interrupt the service on the line which was used for patching, but the importance of maintaining the train wire is so great that any other available wire is used for patching until the defective portion of the train wire can be repaired.

The above describes in a general way the manner in which the telegraph is used in train despatching. We can now specify the requirements which are being met by the telegraph for this service and which the telephone must meet in order to successfully compete. These requirements are:

1. Ability to signal any one of 50 or more stations on a 250-mile (402-km.) line and ability to signal despatcher from any of the stations.

2. Arrangements whereby any number of stations can simultaneously listen in.

3. Means for quickly testing and patching any portion of the circuit which gets into trouble.

In addition to the above requirements, the telephone owing to its greater flexibility can be arranged to permit of other operating advantages not possible with the use of the telegraph. Among these are the following:

a. Provision whereby officials who are not telegraph operators, but who are directly interested in the movement of traffic, as for instance, train masters, yard masters, division superintendents, etc., can listen on the wire and keep in touch with traffic conditions.

b. Arrangements permitting the signaling of stations without interrupting conversation. This feature results in saving a considerable amount of time.

c. Automatic notification to the dispatcher that the station he is calling is receiving the signal.

SIGNALING

The first requirement is the ability to signal any one of 50 or more stations on a 250 mile (402-km.) line.

The problem involved here is selective signaling on a long and very heavily loaded line, and is an extreme condition which has not been met with in commercial practice. When consideration is also given to the degree of reliability required for this service, it will be seen that the development of special apparatus was necessary. The instrument used for this purpose is called a selector and is installed at the substation and so designed that the despatcher at will can cause any selector to operate and close a contact, thereby signaling that station by ringing a bell or causing a signal to be displayed. There are three general types of selectors which have been developed for this purpose, operating on three different principles:

1. Instruments responding only to a certain number and sequence of long and short current impulses or long and short intervals between impulses. In this case the only instrument on the line that would function properly and close its contact would be the one which was adjusted to respond to the particular code arrangement of impulses which were being impressed on the line.

2. Instruments arranged to be started simultaneously by the despatcher and to operate independently but in synchronism with each other by means of local energy at the station. The despatcher's sending device being so arranged that at a predetermined instant one impulse is sent out on the line which at this instant is provided with a path through one selector

contact only, the other selectors either having passed their contacts or not having reached them.

3. Instruments of the so-called step-by-step type which are stepped around in synchronism by a succession of impulses from the despatcher's office, the number of impulses sent determining the station called.

What is known as the Gill selector is an instrument of the first or code impulse type. This device has been used for a number of years to selectively signal telegraph offices, and for this service it is connected in series with the back contact of the telegraph relay and battery. When the proper code is sent over the line, the selector will function and ring the bell, but by using ordinary Morse characters it is practically impossible to reproduce the code and falsely call. As this selector had been pretty well tried out for telegraph service, it was but natural that it should be one of the first used with the telephone. Fig. 1 shows a view of this instrument with the glass cover removed. It consists essentially of a ratchet wheel, an electromagnet whose armature is arranged to step the wheel forward, a retaining pawl to retain the teeth stepped and a mechanical time element whose function it is to permit the retaining pawl to assume either one of two positions, according to the length of the impulse of current.

FIG. 1.—Gill selector

The time element is seen at the right of the instrument and consists of a metal wheel fastened to a small diameter shaft so arranged that it can roll down an inclined rod.

The fact that it is the small diameter shaft of the comparatively large wheel, that rolls down the incline causes the descent to take an appreciable time. When the stepping arm is in its upper position it prevents the wheel from descending, but when it moves to the lower position due to current, the wheel starts to roll and will reach its lower limiting position provided the current impulse is of long enough duration. If, however, the impulse is short, the stepping arm will return to its upper position due to the retractile spring, and prevent the wheel from descending its full distance. It will thus be seen that a long impulse permits the time element to function while a short impulse does not.

Fig. 2 shows a diagrammatic view of the ratchet wheel and retaining pawl. The time element wheel, through a system of levers, is so arranged that it permits the retaining pawl to fall in the ratchet teeth to one half their depth if it is in its upper position and to the full depth if it is in its lower position.

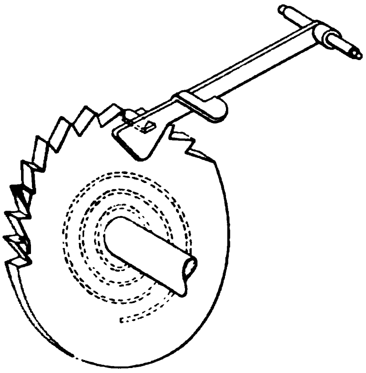


FIG. 2.—Gill selector ratchet wheel

The teeth of the ratchet wheels on the selectors are all cut differently, some are perfect ratchet teeth, some have a diagonal slot sawed in their lower half, while others have the top half of the tooth diagonally cut away. Fastened to the pawl is a semi-circular piece which falls behind the teeth and holds the wheel from returning to normal when the stepping pawl is in its up position, preparatory to making another step. If, however, the lower or upper half of a tooth, against which the piece rests, is diagonally cut away, it will push the pawl to one side and the wheel will return to normal position under the influence of its retractile spring.

In order that the retaining pawl hold each tooth stepped of a given selector, its position with relation to the face of the teeth must be such that at no time does it rest against a portion of a tooth face that has been diagonally cut away. This condition is brought about only in the case of a selector which is being operated by its proper sequence of long and short impulses, and this is the only selector that will close its contact and signal its station.

Fig. 3 shows a despatcher's sending key cabinet with the cover removed. There is a key for each selector and each key consists of a train of gears, whose speed of rotation is controlled by an escapement, and when operated a specially cut code wheel makes one revolution sending out on the line a certain code of impulses.

Fig. 4 shows a schematic diagram of the first type of way-station circuit that was used with this selector. The closure of the contact of the line relay puts local battery current through the selector and steps it around. When the selector contact is made, local current flows through the right-hand spool of the polarized relay closing its contacts and ringing the vibrating bell.

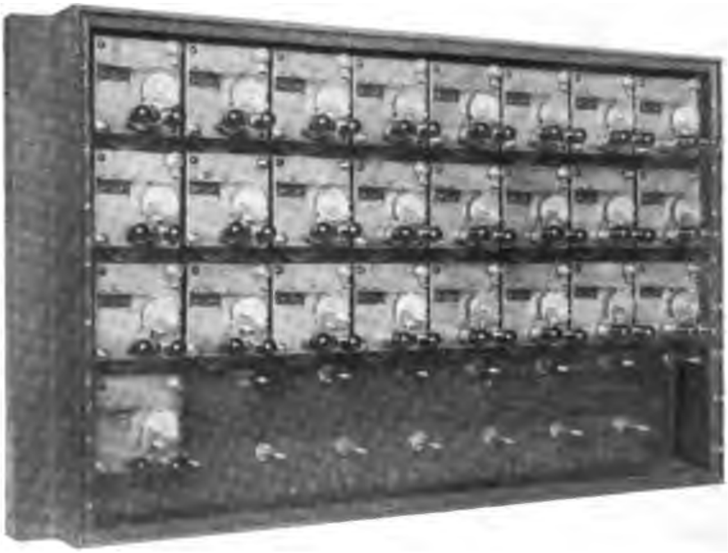


Fig. 3.—Sending keys

The lower relay contact closes the battery through the bell while the upper contact places a shunt on one side of the line around the line relay and through a one-tenth microfarad condenser and vibrating bell contact. This shunt through the vibrating contact introduces a tone on the line and is heard in the despatcher's receiver, thus notifying him that the station bell is being rung.

In the first installations of this type of apparatus the line circuit arrangement was as shown in Fig. 5. It was thought advisable to use a line relay at every station and operate the selectors and bells by local battery. In order that the sending impulses might not introduce enough niose in the receiver bridges to interfere with conversation while the despatcher was signaling and also to permit each line relay to receive the same amount of current, a grounded simplexing arrangement was used for signaling, the relays being placed in series with the line. Relays at alternate stations were connected in opposite sides of the line, so as to maintain balance as nearly as possible. With ordinary relays placed in series, the transmission loss would, of course, be very considerable. The relays used therefore on the first installations were of a sensitive type having an inductive winding of 20 ohms and a non-inductive shunt of 30 ohms. This was, in fact, a type of telephone supervisory relay, and from a transmission standpoint was the most efficient relay available. Although the transmission loss in the relay was reduced to a minimum, it was still appreciable especially on a long line with many stations and several receivers off the hook. In addition to this, the shunt winding of the relay made a very inefficient arrangement for operation, as, of course, the signaling current going through the non-inductive shunt represented a clear waste. Another objection to this circuit that was found in practice was noise introduced from the grounds and unbalance, as it is almost impossible to balance the line with series relays. Also the effect of lightning on the series arrangement was found to be rather disastrous. The troubles experienced with this

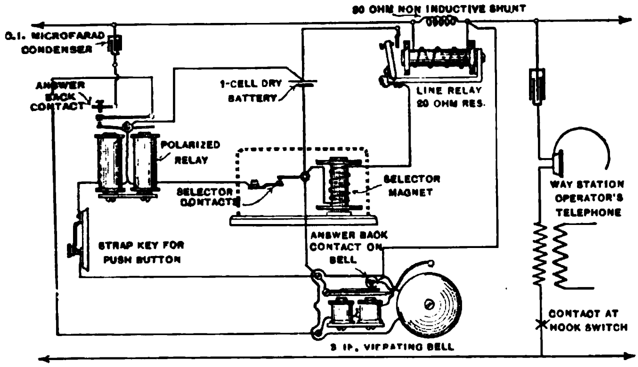


FIG. 4.—Sub-station circuit

circuit finally led to the development of a new circuit, as shown in Fig. 6. In this arrangement there are no grounds on the line and no line relays used. The selectors are wound to 4,500 ohms resistance and placed directly across the line. In series with the selectors is placed the proper amount of tapering resistance, so that the amount of signaling current through each bridge will be the same.

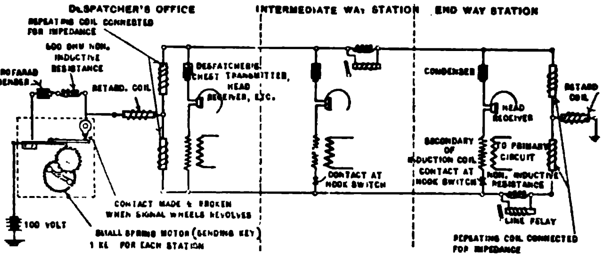


FIG. 5.—Line circuit

The answer back is obtained by including, in series with the selector contact bell and battery, a secondary winding on the spools of the selector. As the bell vibrates it induces current in the selector windings which produces a tone in the despatcher's receiver. With this circuit arrangement the normal current for the operation of the selectors is ten milliamperes. The current, however, can fall considerably below this without affecting the operation of the selectors. The retardation coils and condensers at the despatcher's end of the line are used to cut down the peak of the current wave to such a point that the noise in the receivers while the signal is being sent is not enough to interfere with conversation. In this circuit it is necessary to introduce a condenser in series with the receivers across the line in order that the signaling current may not be shunted through the talking bridges.

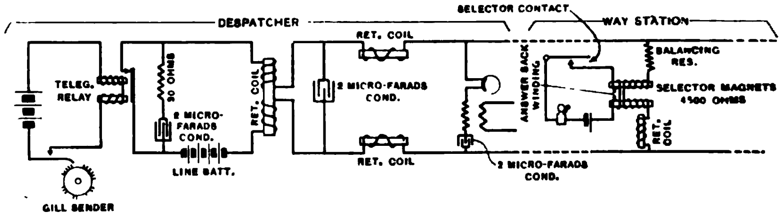


FIG. 6.—New line circuit

The second type of selector which has been extensively used, that is, selectors maintained in synchronism by local energy at the substation, is what is known as the Wray-Cummings selector. Fig. 7 shows the despatcher's master sending outfit and Fig. 8 shows the substation selector. The master selector consists of a standard clock-work mechanism, to the second hand of which is attached a contact arm. In the path of this contact there are thirty insulated segments which are arranged so that any one of them can close battery current through a relay when the contact arm engages with this particular segment. The despatcher despresses any of the locking push buttons shown at the right of the figure and then operates the key mechanism shown on the door. This mechanism is merely a retardation device arranged so that when operated a contact is made for a length of time sufficient to operate the relays which start the master and all the station clocks. The substation selector is similar to the despatcher's clock mechanism except that each station is equipped with but one contact arranged to engage with the revolving arm. These contacts at the various stations are adjusted at different angular displacements from the normal position of the contact arm. When the despatcher has started all the clocks simultaneously, it is evident that the contact arm on the master selector will have reached, say its tenth point at the same instant that the tenth selector has reached its point. At this instant there are no other selectors which are on their contact point and due to the fact that the tenth point on the despatcher's clock is connected by means of a locked push button to cause current to flow on the line, the signaling mechanism at the desired station will be operated. Fig. 9 shows the circuit arrangement at the despatcher's office and at the way-station.

FIG. 7.—Wray-Cummings despatchers keys

When properly adjusted this selector has given satisfactory service. It, however, requires one minute to call the thirtieth station.

The third class, or step-by-step selector, is represented in Fig. 10 which shows the Western Electric selector. This device is probably the simplest and quickest so far used for this purpose and consists of two electromagnets connected in series and mounted in a brass frame. Each magnet is equipped with two spools, the cores of one of the magnets being covered with copper sleeves to produce slow action. Fig. 11 shows the schematic diagram of the lever movements. Upon the fast-acting lever is mounted a stepping pawl *A* designed to engage with a ratchet wheel to which is fastened a platinum pointed arm. Mounted on the framework is a retaining pawl *B* designed to retain the teeth as they are stepped. Attached to the slow-acting armature are two fingers designed to engage with the two pawls in such a way that when in the normal position of the slow acting armature, the two pawls will be held out of engagement with the wheel, while in the operated position the fingers will permit the pawls to engage with the wheel. This selector is operated by first placing on the line an impulse of current which operates both magnets. There is then placed on the line a succession of short

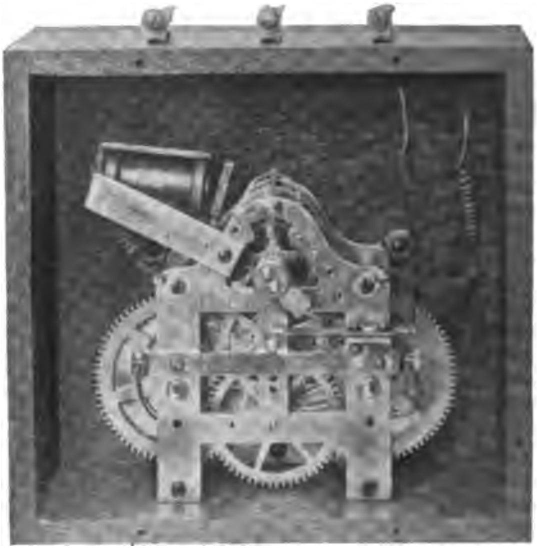


FIG. 8.—Wray-Cummings selector

impulses, which cause the stepping magnet to oscillate back and forth and step the wheel around the desired number of steps. The speed with which these impulses are placed upon the line however, does not permit of the slow-acting magnet releasing. When the desired number of steps are taken, the contact is made and current is held on the line, thus ringing the bell.

As soon as current is removed from the line the slow-acting magnet releases, which raises the pawls and permits the wheel to fall back to normal position under the influence of its retractile spring. When a station is called, say for instance No. 10, all the selectors take ten steps and the selectors at the first nine stations will momentarily make their contacts as they step around; thus momentarily the local station battery circuit is closed at these stations. This, however, will not cause the bell to ring for the following reason: The selector operates at the rate of from 8 to 10 steps per second, and the arrangement of the contact spring *C*, Fig. 11, is such that it follows the movement of the stepping lever and during a stepping cycle makes contact with the contact arm in but a small percentage of the one-tenth of a second necessary to take a step. This action is of such momentary duration that there is no danger of a false signal being given. It will be noted that the contact arm of the wheel in its normal position rests against an insulated contact or stop piece. On the other side of this stop piece is fastened a platinum contact which will engage with the contact arm when the wheel has

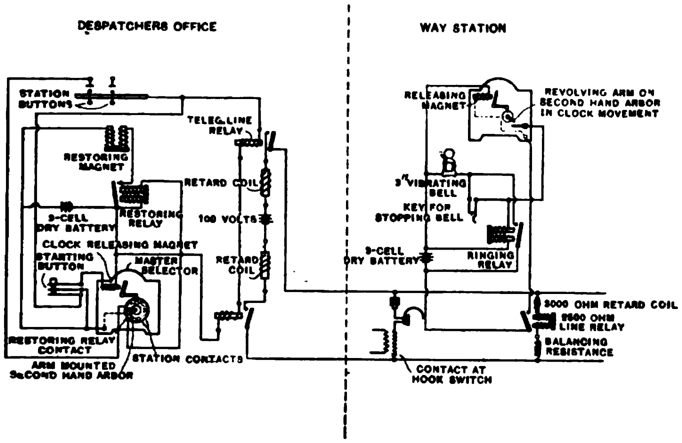


Fig. 9.—Wray-Cummings circuit

gone around to its limiting position. This stop piece is angularly adjustable and permits easy adjustment of any selector for any station. It is sometimes necessary, as will be explained later, to produce a simultaneous signal at all the stations and that is the function of the contact on the stop piece, it being only necessary to send out the proper number of impulses on the line which will cause all the selectors to engage with this contact.

Fig. 12 shows the local battery way-station circuit used with this selector. There are two 40-ohm retardation coils placed on either side of the selector as a protection against lightning. The selector is wound to 3,750 ohms and is connected with the proper taper resistance to produce equal current in all the bridges. When a station is called, contact *A* is made, which closes the local battery through the vibrating bell. The bell is also equipped with a front contact which makes and breaks a 10,000-ohm resistance across the line and gives the despatcher an answer back.

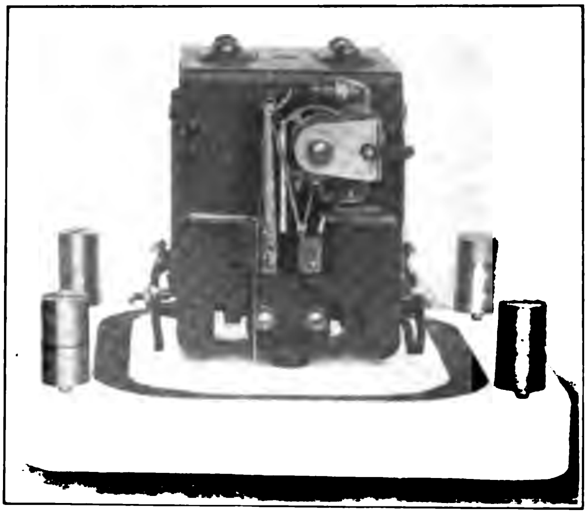


FIG. 10.—Western Electric selector

This selector is also arranged to ring a bell by means of the battery located at the despatcher's office, thus eliminating the local battery at the substation. Fig. 13 shows the apparatus so arranged. When using central battery to ring the bell it is necessary, of course, to have it high wound. In this case, its resistance is 1100 ohms and a taper resistance is used in series to produce the same current through the bell wherever it may be located on the line. It was found that if the taper resistance used for the selector was also used for the bell, the drop in voltage due to the combined current passing through the resistance was great enough to reduce the current to an objectionable extent. Separate taper resistances are, therefore, used on the bell circuit. Fig. 14 shows the despatcher's sending key, one being used for each station. These keys are mounted by means of a latch in a suitable cabinet and can be individually and quickly removed without disturbing electrical connections. They consist of a train of gears whose speed is controlled by an improved silent governor. The contact wheels are the same in all keys of a given type but are adjusted for each station by moving the segments so as to uncover the proper number of teeth for the station desired.

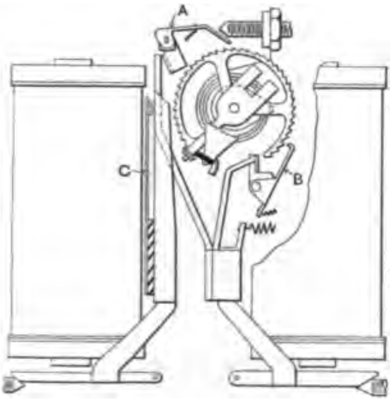


Fig. 11.—Lever movements of W. E. selector

This feature makes the keys universal and as the selectors are easily adjustable to any station, they are also universal, and a spare selector and key kept on hand can be arranged quickly to replace any selector or key which may become defective.

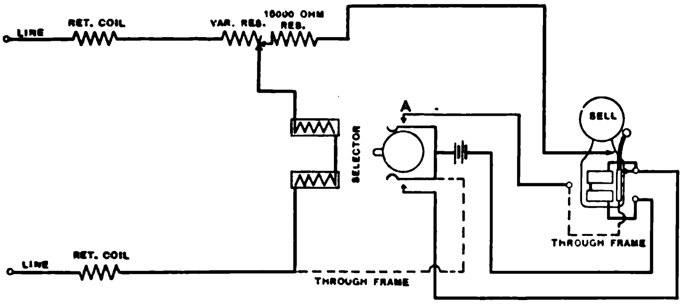


Fig. 12.—W. E. substation circuit (local battery)

Fig. 15 shows the despatcher's and line circuit. The contacts of the sending keys are all arranged in parallel so that the operation of any one will cause the sending relay to operate and place main battery current on the line. Capacity and resistances are placed around the contacts to reduce the sparking. The noise of sending is reduced by leading the battery current through three retardation coils and placing six-microfarad condensers across the line. It was found that if on a despatching wire the line should from any cause break, leaving but few selectors on the line, the current through the selector bridges would rise to such a point, due to the fact that the total voltage was still used, that the selector stepping armature would stay in its forward position when stepping impulses were sent on the line instead of oscillating and stepping the wheel. This was a serious objection as, in case of an accident of this kind, the despatcher would be unable to call the stations between him and the

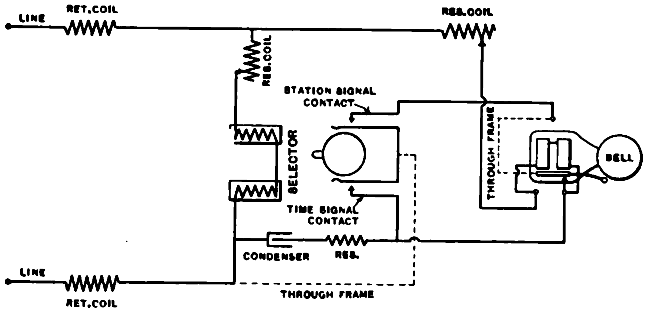


FIG. 13.—W. E. Substation circuit (central ring)

FIG. 14.—W. E. sending key

break. It was found that this sticking occurred more or less in all types of selector operated by impulse from the despatcher's office. The fault was overcome to a certain extent with the Western Electric selector by designing the magnetic circuit of the selector so that under normal current it would be fairly near saturation, excessive current not increasing the pull of the armature very much. This remedied the objection somewhat, but upon further investigation, it was found that with excessive current going to the line, the six-microfarad condensers, used for quieting the circuit at the despatcher's office, becoming more highly charged under this extreme condition, tended to hold the selectors up during intervals between stepping, due to their discharge over the line and through the bridges. In order to counteract this effect, the sending relay was equipped with an extra contact *A* so constructed that the closure of the battery contact *B* caused the opening of *A*, and the instant that contact *B* broke, contact *A* made. In series with contact *A* across the line was placed a 250-ohm resistance. This arrangement provides a comparatively low resistance path for the discharge of the condensers and prevents their discharging to any great extent throughout the line and holding the selectors up.

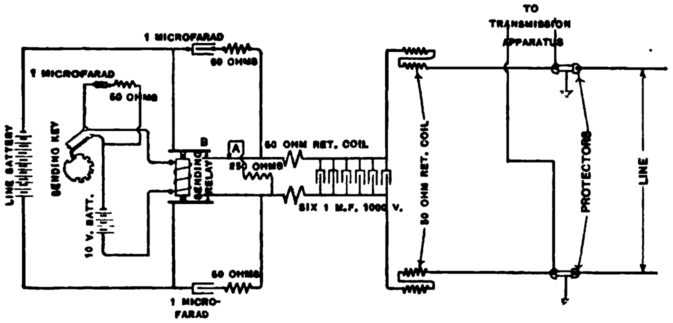


FIG. 15,—W. E. despatchers and line circuit

In addition to the three types of selectors described, there are polarized types of selectors which I believe have been used to a small extent. This type of selector generally employs current of one polarity for stepping and of the opposite polarity for ringing. The objection which has been brought forth against polarized apparatus has been that it is necessary to maintain the line poled in one direction all the time, as a reversal of the line wires will cause all the selectors beyond this point to fail.

The liability of reversing lines due to line repairs, patching, etc., seems to be great enough to raise a serious objection to polarized apparatus.

The foregoing description covers in general the means used by the despatcher for signaling the various stations. The tower operator, when he wants to communicate with the despatcher, listens in to learn whether the line is busy, and if it is not, he merely says " despatcher " in the transmitter. The despatcher wears a head receiver and central office type of chest transmitter and is on the line all the time.

The second requirement which must be met by the telephone as used on a train wire are means whereby any number of stations can simultaneously listen in.

As we will have to refer to transmission values it might be well at this point to explain the units used.

In giving a value to a certain quality and volume of transmission it is said to equal a certain number of miles of cable. This means that the number of miles stated is such that when standard instruments are used for this distance over No. 19 gauge telephone cable of 0.06 microfarads capacity per mile, the value of transmission will be the same. It is considered that the commercial limit of good transmission is 30 cable-miles. This value can be equated in terms of any other kind of circuit. One mile-cable loss is equivalent to the loss sustained in 16 miles (25.7 km.) of No. 9 B. & S. copper and as this is the standard size of wire used on despatching circuits, it will be seen that the line may be 480 miles (772 km.) long before the so-called commercial limit is reached. This is considerably longer than any of the circuits in use, there being but few over 250 miles (402 km.) in length. There is, therefore, a surplus of transmission available which can be taken advantage of in arranging circuits to permit several operators to listen in simultaneously. The loss occasioned by the selector bridges is almost negligible, the impedance to talking frequencies of the W. E. selector being about 90,000 ohms. This value is such, that the loss sustained when forty selectors are across the line is only one mile of cable.

The first form of substation talking circuit used on train wires was the standard local battery circuit, which is schematically shown in Fig. 16. It will be seen that during conversation, the condenser, receiver and secondary of the induction coil are in series. The resistance of the secondary of the coil used was 20 ohms, and of the receiver 70 ohms, a two-microfarad condenser being used in series. The total impedance of this bridge to talking current is approximately 600 ohms, about 300 ohms of which are active for receiving purposes. It is obvious that when a number of these sets are bridged across the line at once, the joint impedance of the parallel paths is very low and the transmission correspondingly difficult between widely separated stations.

The first step towards overcoming this difficulty was to raise the impedance of the talking bridge by the use of a different induction coil, wound with a low primary and a high impedance secondary. This bettered matters somewhat as the higher resistance bridges produced a more even distribution of the talking current from the despatcher's office, and would give better outgoing transmission from the substations. Although the despatcher's voice currents were undoubtedly better distributed among the bridges with this arrangement, still, due to the fact that the bulk of the impedance in the bridges was in the secondary of the coil, the receiver having a resistance of but 70 ohms, the transmission gain was very slight.

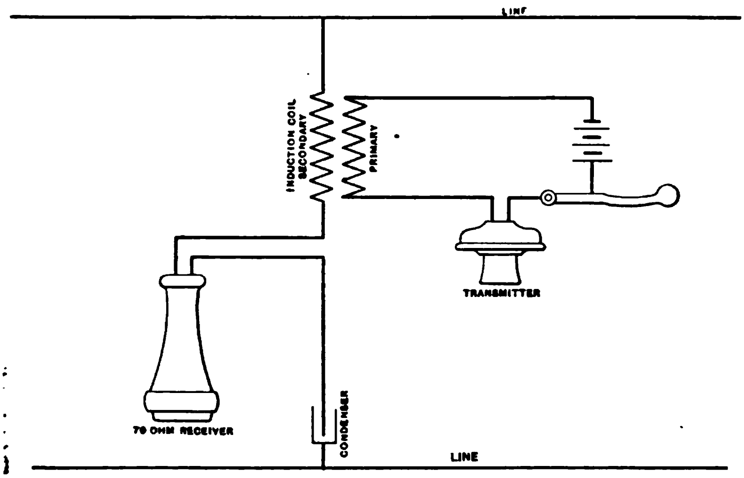


FIG. 16.—Local battery telephone circuit

The next obvious step would be to maintain the high impedance in the talking bridge but put as much of this impedance as possible in the receiver. If this were done, however, the high impedance receiver in series with the secondary of the induction coil would reduce the outgoing transmission from the substation to an objectionable extent. It was then determined that the best results, both for receiving and transmitting, would be obtained by installing a switching arrangement at the substation so that when the switch was in one position the circuit was in the best possible condition for receiving and when in the other position was in the best possible condition for transmitting. The circuit developed is shown in Fig. 17, the circuit to the left representing the despatcher's station and to the right the way station.

It will be noted that a non-locking push button is located at the way station and in its normal position the bridge across the line consists merely of a 700-ohm receiver and a one-microfarad condenser. The impedance of this receiver is about 2500 ohms and as the total impedance of the bridge is all in the receiver it is all effective for receiving purposes.

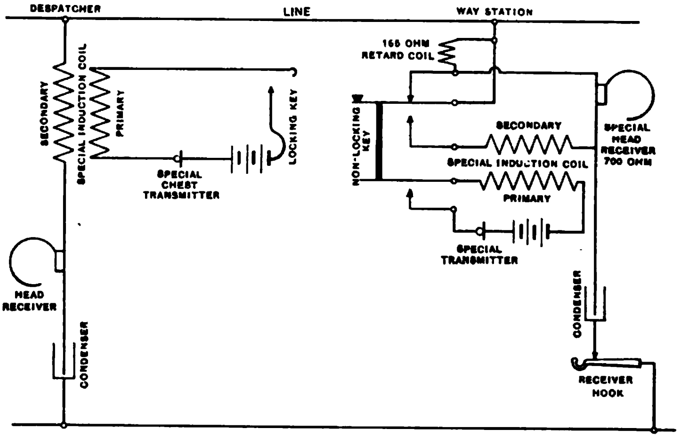


Fig. 17.—W. E. Train despatching way station circuit

When the operator wishes to talk he depresses the push button or in some cases a foot switch which closes his local transmitter battery circuit and also connects the secondary of his induction coil to the line. The voice currents generated in the secondary have a path directly across the line in series with the condenser and also a shunt path through the retardation coil and receiver in series. This retardation coil is of about 6,000 ohms impedance and is placed in series with the receiver in the manner shown, in order that the despatcher may break in if it is necessary for him to interrupt an operator while talking. The impedance values are such that the amount of side tone is just sufficient for the operator to distinguish the despatcher's voice if he interrupts and he will release his button in order to clearly understand what the despatcher is saying. The outgoing transmission of this circuit is, therefore, the best possible consistent with the fact that we must arrange to permit the despatcher to interrupt the operator's conversation when necessary.

The induction coil used in the way-station and also the transmitter are especially designed for railway work. The transmitter button is of medium resistance and while not taking excessive battery current still varies the current through a large range and gives good volume and articulation with three cells of battery.

When the receiver is off the hook, this circuit reduces the transmission by about one mile of cable, for stations beyond, that are receiving from the despatcher. 130 miles (209 km.) No. 9 copper being the average length of despatcher's line, the line transmission loss at 16 miles (25.7 km.) of wire to one mile (1.6 km.) of cable, will be eight miles (12.8 km.) of cable, leaving an equivalent in transmission of 22 miles of cable that can be used in the bridges before we reach 30-mile (48-km.) transmission for the last station. Thus it will be seen that on a line of this kind 22 operators can be listening in and good transmission can be maintained. It is practically never necessary that this number be on the line, 15 being a liberal estimate of the number of receivers that will be off the hook at one time. If, however, emergencies should arise making it necessary for 25 or 30 operators to listen in, transmission will be sufficiently good for the transaction of business, even though it is beyond the 30-mile limit.

The requirements of the despatcher's circuit are somewhat different from those at the towers. He must be on the line all the time and the transmission and receiving of his set must be as good as possible, without resorting to the use of a push button for talking and listening, as his time is too fully occupied to permit him to use this device.

The circuit is shown at the left of the figure. A 70-ohm receiver is used in series with the secondary of the same type of induction coil, as is used at the substations, and a one-microfarad condenser in series. The impedance of this bridge is about 650 ohms and it being the lowest on the line, the receiving will be good. This value also permits good transmitting. The switch shown in the figure is of the locking type and opens the battery circuit when the set is not in use. Another form of the substation circuit developed for the way-station is shown in Fig. 18. This arrangement is somewhat similar to the one previously described and contains a push button to operate when talking. Under normal conditions, that is, when the push button contacts are open, the path of incoming voice currents is through the adjustable retardation coil, 70-ohm receiver, secondary of the induction coil and condenser. The impedance of this retardation coil is adjustable by means of a sliding core and the various stations are adjusted with reference to their distance from the despatcher's office, the furthest station on the line having the least impedance. When the button is depressed for talking the transmitter battery is closed and a retardation coil is placed in shunt around the adjustable coil and receiver. This cuts down the impedance of the bridge for outgoing voice currents and still permits of enough side tone so that the despatcher can break in on the conversation. The impedance of the bridge under these conditions, however, is considerably higher than in the previous circuit described and for this reason it is advisable to use more local battery current, as many as eight cells being sometimes used for this purpose. This, of course, is somewhat objectionable in that it tends to decrease the life of the transmitter. The impedance of the receiving bridge with the core all in the adjustable retardation coil, is about 4,300 ohms, and all out is 1,200 ohms. A bridge of 4,300 ohms is equivalent to 0.6 mile-cable loss and 1200 ohms to 1.8 mile loss, or an average of 1.2 mile loss for each station on this circuit.

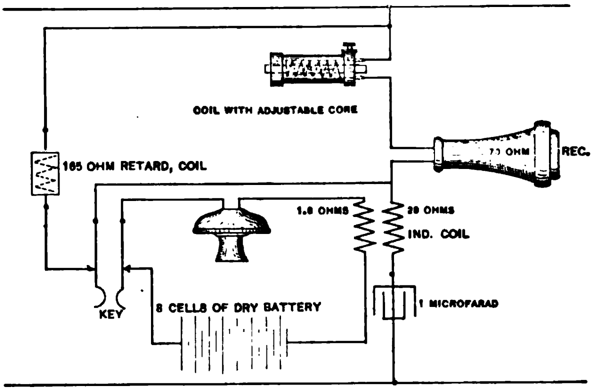


FIG. 18.—Adjustable coil way station circuit

PATCHING

In order to facilitate testing and maintain service on the train wire in the case of line trouble, it is customary to loop the various lines on the pole into every station or every few stations, through patching boxes. A typical box is shown in Fig. 19 and its circuit arrangement in Fig. 20. The wires entering the tower are connected to the jacks at the left, the connection passing through the cutoff contact to the jack at the right and from thence back on the pole line. Two locking keys are provided, arranged so that the selector and telephone set are normally connected to the train wires but by operating the key they are connected to two pairs of cords. When a train wire gets into trouble, the operator can cut off the line beyond his station by inserting any plug in either one of the train wire jacks. This operates the cutoff contact and opens the line. When the trouble is located between any two towers, the operator at the tower nearer to the despatcher throws his key, placing a plug of one pair in the incoming train wire and the other plug of this pair into the wire which he is going to use for patching. He also places one plug of the other pair in the other side of the incoming wire, placing its mate in the other side of the outgoing wire. This will connect the incoming train wires to the outgoing pair of wires to be used for patching. The operator on the other side of the break, plugs in in such a way that the patching wire is again connected onto the train wire. The patching box is equipped with a grounding jack so that any line can be grounded for test.


FIG. 19.—Patching box

The foregoing describes in a general way the manner in which the telephone has been adapted for use on train wires. The second class of service in which the telephone is replacing the telegraph is on message wires.

MESSAGE WIRES

A telegraph message wire extends throughout a division and is generally cut in to all the offices on the division. It is used for the transaction of miscellaneous railway business between division and intermediate points. It is also used in a great many cases for sending commercial telegraph messages, when the railroad and telegraph companies employ joint operators. In addition to the above uses, the message wire is usually used for sending time to the various towers. It is extremely important that the clocks at the offices along the line be correct, as even a comparatively slight difference in the indicated time between the despatchers' and substation offices may cause serious results to follow. In order that the accuracy of the various clocks may be regularly checked at a certain time each day, and on some roads twice a day, a certain number and arrangement of dots are sent out on the telegraph line in such a way that they indicate to the various operators the exact time, thus permitting the operators to properly set their clocks, if such action is necessary. From the above it will be seen that the requirements which the telephone must meet for this class of service are:

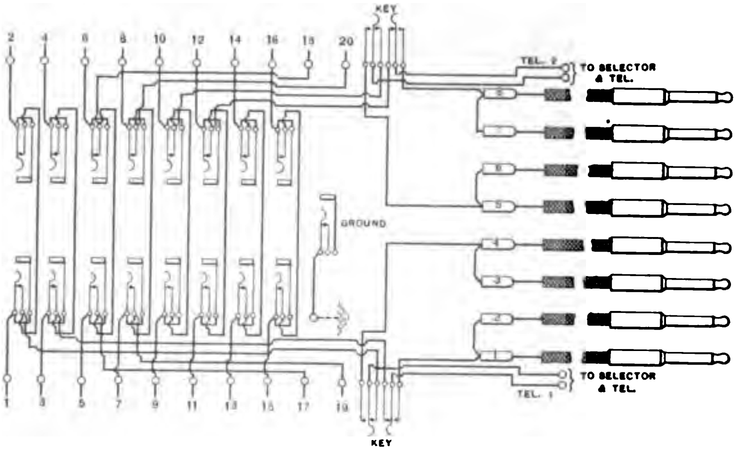


FIG. 20.—Patching box circuit

1. To selectively signal on a line whose characteristics are in general the same as a train wire, but that the selective signaling should be capable of being performed by any operator on the line. In other words, selective signaling arranged for intercommunicating work.

2. The ability to simultaneously signal all the operators so that time may be given.

The telephone has been in use for message work on a number of wires in which all the calling is done by one operator, thereby differing somewhat from telegraph operation. Circuits, however, have recently been developed for inter-communicating work which give satisfactory service. Probably the one having the widest margin of operation was developed in connection with the step-by-step selector and is shown in Fig. 21.

The condensers and retardation coils at the despatcher's end, for reducing the noise of sending, are arranged practically as in the standard train wire circuit. Each substation is equipped with a sending key, so connected that its operation will place impulses on the line from ground through the center of the resistance, over both sides of the line, through the point A, thence through the battery and sending relay to ground. The operation of this relay places current impulses metallically on the line and operates the selectors at the various stations, the selector used being the standard type used on train wires. Modifications of this circuit arrangement are in use for this purpose but the difficulty that has heretofore been encountered has been that with a grounded relay, the line leaks are liable to be sufficient to either operate the relay or hold it in its operated position. The glass insulators on a pole line along the right of way of a railway are constantly subjected to the smoke and soot from the locomotives. This almost invariably causes the insulators to become permanently coated with soot and when wet weather sets in, the leaks to ground on railroad lines probably average considerably higher than is found to be the case in commercial

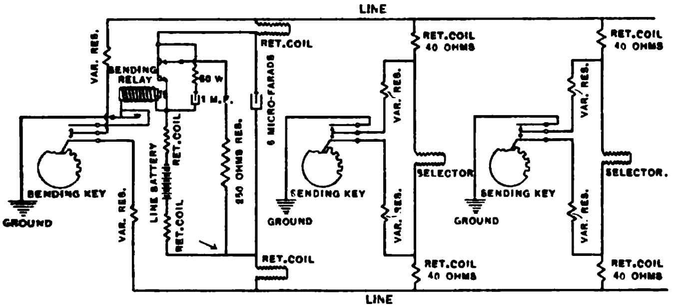


Fig. 21.—Western Electric Intercommunicating circuit

practice. The circuit shown was designed to neutralize as much as possible the effects of line leakage in so far as it affected operation. It will be noted that when any station is sending, current flows from ground of that station over the upper line wire as shown in the figure, to a normally closed contact of the relay, through this contact to the point *A* on the lower line wire, and then through battery and relay to ground. The contact arrangement is such that the making of the normally open contact breaks the normally closed. This cuts off the current from the upper line wire and doubles the resistance for grounded current, thereby, cutting the current through the relay in half. The relay being in its operated position, this current is sufficient to hold it. As the first effect of line leaks would be to hold the ground relay closed when it was operated, the arrangement shown largely overcomes this tendency. The taper resistances used in connection with the keys at the substation are arranged so as to give the grounded relay the same current from any substation. The curves shown in Fig. 22 show the margins of operation of this system for various lengths of line and operating voltages. For an average line of 130 miles (209 km.) and 160 volts, the line leaks can be as low as 125,000 ohms per mile, without interfering with operation. This is equivalent to about 960 ohms ground leak, which is a value that would seldom be met with in practice.

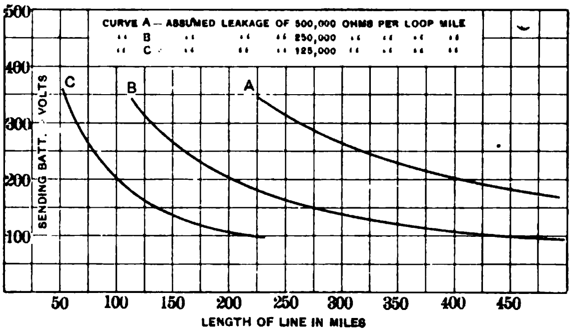


Fig. 22.—Intercommunicating system. Curves show relation between line voltage and length of line. System can be operated over assuming a definite leakage per loop mile (with no readjustment of sending relay).

The manner of sending out time is as follows: Referring to Fig. 12, which is the local substation circuit of the Western

Electric selector, it will be noted that when the selector closes the lower contact, the local battery current goes through the bell winding but in its path is not included the vibrating contact. This will cause the bell to become single stroke in action.

Referring to Fig. 11 which shows the selector, the platinum contact on the stop piece will be made simultaneously on all the selectors when a sufficient number of impulses have been placed on the line. When time is to be sent, the Wire Chief at the division point operates a special key which steps all the selectors around to their time contact point and holds current on the line. The circuit at the division point is so arranged that the contact of the telegraph relay receiving time makes and breaks the current on the message wire. The interval of no current on the line is so short that the slow acting member of the selector does not fall back, but the time contact is made and broken, which taps the bell, and reproduces the signals which were formerly heard on the sounder.

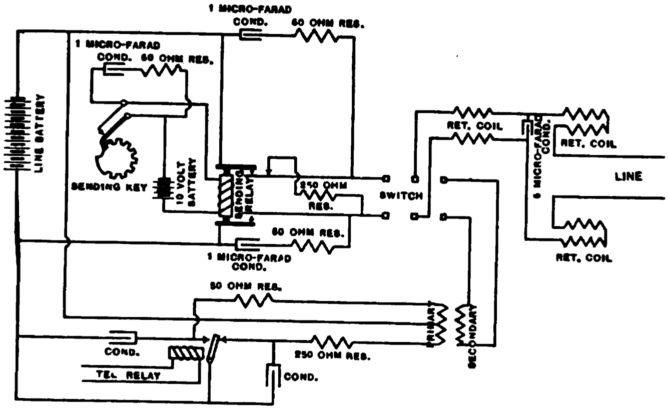


FIG. 23.—Time sending circuit

This is the method used to send time when local battery bells are used. If the same manner of tapping the bells were employed in circuits where way-station bells are rung by the despatcher's battery, the amount of current required to operate all the selectors and ring all the bells at once, would tend to cause such an excessive current flow that the amount of voltage drop on long lines would be such that satisfactory operation could not be obtained. Another arrangement, Fig. 23, was therefore developed for sending time on the central ringing systems. When time is to be sent on the line, the Wire Chief at the division point throws a switch which connects up the circuit as shown. The secondary of a repeating coil or transformer is connected across the line and the middle point of its primary connected to one side of the main battery, the other two ends of the primary winding being connected to the front and back contact of the telegraph relay, which operates in accordance with the time impulses being sent from the distant point. Resistances are introduced in the leads from the relay contacts in order to limit the amount of current and condensers are used to reduce the sparking. It will be seen that as the relay operates, there will be generated in the secondary of the coil and sent out on the line an impulse or kick, alternating in character. There is placed in series with the selector at each of the substations an ordinary 1000-ohm polarized telephone bell. These bells are operated every time a secondary impulse is sent out. After time has been given and the Wire Chief has opened his switches, leaving the lines in normal condition, the first impulse sent out by the despatcher when he calls a station, may be of such polarity that it will cause some of the bells to tap. There will only be one tap heard, however, as the bells will remain in the position to which they have moved. This circuit arrangement obviates any danger of stepping the selectors up which might be the case where the contacts of the time repeating relay connected directly on the line. The fact that the polarized bells at the substations are unbiased and will not be affected by reversal of line wires, is another advantage of this system.

Up to the present time, most of the railroads are still giving time over the telegraph as there are but few instances of divisions where there are no longer telegraph instruments in the towers. There are, however, divisions on some roads in which the telephone has replaced the telegraph entirely, and on these divisions, time is being given over the telephone circuit.

In addition to the use of the telephone for train despatching and message work, it has also come into very extensive use for block wire service.

Block Wires

The length of a block wire ranges from one-half mile (0.8 km.) to six or eight miles (9.6 or 12.8 km.) and the service required of the telephone for blocking purposes is merely to maintain communication between two block towers. There are no new features required of the telephone for this work. A great many of the roads are using the existing telegraph wire between blocks for a grounded telephone circuit. This will, of course, introduce some noise in the telephone, but the line being short, this is not generally objected to. If a satisfactory loud-speaking receiver could be produced, it would undoubtedly be very generally used for blocking purposes. If this instrument were used, no signaling device would be necessary, as by simply throwing a key and talking into this transmitter, an operator can call the adjacent tower. This arrangement would also have the advantage

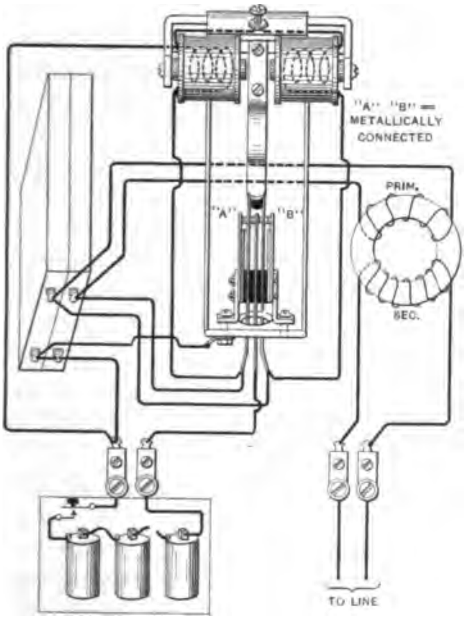


Fig. 4.—Substation circuit

of permitting the operator to be handling his levers or doing other work, and still receive the message. Loud speakers have recently been developed and are now being experimentally tried out on a division of one of the roads. The results so far obtained indicate that it will be advantageous to use these instruments for blocking service.

It is very often the case that besides the block wire, there are one or two short party lines reaching from the tower to siding telephones, residences of employees, etc. The hand generator and code signaling is in general use for signaling between blocks and on these party lines. In order to relieve the load of the operator somewhat, an interrupter has been developed, and is arranged so that code ringing can be performed by means of a push button. Fig. 24 shows a schematic diagram of this interrupter. A very efficient type of transformer is used in this instrument, and with six dry cells in the primary circuit, twenty 2,500-ohm bells can be rung on a 500-ohm line.

In addition to the service performed by the telephone on railroads, as has been described in this paper, it has facilitated railroad business in several other ways. Telephones are used very extensively at sidings. These telephones are generally connected with the despatcher's wire and train crews can immediately get in touch with the despatcher, and a great amount of time can be saved. There has been put on the market a semaphore type of signal in the base of which is mounted a telephone and selector equipment. In case the despatcher wants to stop a train and call the conductor to the telephone, he can do so by operating the selector which throws the signal.

Portable telephones have also come into pretty general use. On some roads, every train carries a portable telephone and a line pole. The line pole is jointed for convenience in carrying and can be quickly assembled for use. It is equipped with two metallic hooks at its upper end which the conductor can connect with the despatcher's wires on the pole line and thereby get into communication with him.

Although the telephone has been in use on railroad divisions for less than four years, it has proven to have a great many advantages over the telegraph which the railroads were quick to appreciate, and at the present time, there are about 37,000 miles (59,545 km.) of road equipped with the telephone, and there have been no instances so far in which accident of any kind can be traced to the use of the telephone for railroad work.

DISCUSSION ON "SOME RECENT DEVELOPMENTS IN RAILWAY TELEPHONY," LOS ANGELES, CAL., APRIL 27, 1911.

Kempster B. Miller: The matter of railway train dispatching, discussed by Mr. Brown in his paper, is one of great importance, not only to telephone men, but to railway people and the public at large. There is an impressive mileage of railroads, important railroads, that are now being operated by telephone rather than by the telegraph, and this fact is surprising to those who have not watched and been in close touch with the development of this branch of telephony.

An interesting thing in the discussion of the power transmission papers, day before yesterday, was that some companies had seen fit to build a separate pole line for the telephone circuit, distinct from the power transmission line. That is not because it is impossible to put telephone wires on transmission poles and get fairly good service, but in order to effect an extra precaution to insure telephone transmission at the time it is most needed. In many cases that is not done—I should say in the great majority of cases. Now, if the power transmission companies are, for added security, willing to build a separate pole line for telephone circuits when they already have a high grade line, the question naturally arises in my mind in regard to this telephone railway train dispatching, is it wise for the railroads to load up the talking circuit with the selective ringing apparatus? I see no reason for even suggesting the building of another pole line in the case of railway circuits; but it does seem to me that in many cases the building of a separate copper circuit, or iron if the conditions warrant iron, for operating the selective bells would be warranted. This separate circuit for the operation of the selective bells on the dispatching system, would prevent loading down, with ringing apparatus, a circuit already overloaded with a multiplicity of bridged talking circuits. I understand that some railroads are doing it but that many others have refused to spend the necessary amount of money. In view of the extreme importance, particularly from the standpoint of the safety of the public, I think this phase of the subject worth discussion.

L. B. Cramer: I have not much to say in regard to this paper, as the experience that I have had with the system is not of very long duration, because the line was not entirely completed when I left to come here; but I have a few questions to ask Mr. Brown.

One thing that I do not entirely agree with Mr. Brown in is his statement that the "arrangements permitting the signaling of stations without interrupting conversation results in a saving of a considerable amount of time."

So far as my observation has been concerned, that seems to be more of a salesman's talking point than a reality in operation. Perhaps you might be able to talk while the man is signaling, but once he is finished and the man at the other end has an opportunity to say, "What was that?" and then all of it has to be repeated. Perhaps I have not had enough experience or perhaps our line is not in proper tune to take care of this, but at present that seems to be one thing that does not work out as it is supposed to—that is, the way the company represented the apparatus said it would work.

I have also noticed, in regard to the ringing of the bell at the station called, the sending keys are made of such a size, that if they were made a little larger they would not make a cabinet of extremely large dimensions and the amount of space that can be given to them would then be enough to produce a ring long enough to call the operator. I notice our dispatcher often calls a second and even a third time. In case of substations, where the bell is mounted on a booth, there being some noise in the machines, we have an auxiliary bell that makes plenty of noise and the substations are the stations from which we get the best responses.

In regard to the switches, which have one position for receiving and one for transmitting I have already thought of making some changes in the apparatus because in stations where we have a set that is mounted on a desk, about the second or third day after the telephone is in operation the agents get a ruler or a stick and plug the button. This, perhaps, could be made a subject of discipline and, taken care of in that way, and you could get the result which you are supposed to get by being able to hear better by leaving the button in normal position and only press the button in when you are talking. The agent and operator will do these things and when there is a train coming, or anyone whom they think will see it, they will take the plug out; but ordinarily, they will leave it plugged up so when they want to O. S. a train, they will not have to work the plug.

Another thing that I would like to ask Mr. Brown is in regard to the retardation coils. We made some tests on another railway where their telephone circuit is carried on the same poles as the 33,000-volt transmission system. We made tests of two different companys' apparatus. In the type of apparatus which the author describes I notice they used three retardation coils. On that particular test the man had about 80 miles of telephone line and he was unable to produce results to any great extent, while another company's representative with apparatus similar to this one, but on which he used only one retardation coil, he was able to handle his calling without any trouble and the transmission seemed to be first class. Now, whether there was something in the atmospheric conditions at the time when these different tests were made, or whether it was just a case of some operator's interfering—that is one thing that some of the telegraph operators will try to do. If they know you are trying out a telephone which will do away with their job as telegraph operator, they will resort to almost any means to put the telephone out of commission. We have no trouble in using the telephone in connection with the telegraph, where the telephone is used mostly for handling messages pertaining to freight shipments and dispatching power.

Ralph Bennett: This system was offered to me about two years ago, for use in connection with the transmission line telephone. We did not adopt it. There were a number of questions that came up that the manufacturers could not answer. We have on our telephone line a pressure of about 2,000 volts to the ground, and 600 micro-amperes unbalanced current flow. The line is noisy. When we had trouble on the line we would have additional voltages. The manufacturer could not state how we could repair his sets with the men we had. He could not state definitely his apparatus would satisfactorily select in the presence of those large currents under heavy pressure in this transmission line. I would ask Mr. Brown whether these things could not be handled as the securing of a telephone which will call and select stations for transmission line work is very important.

Ralph W. Pope: Mr. Chairman, there does not seem to be anyone here to take up the telegraph operators' view of the situation.

Now it has been my experience in my fifty years of knowledge of the Morse telegraph, that the people who do not understand it and work it don't appreciate what a beautiful and simple method it is of transmitting communications. It may be of a little bit of interest—add a personal touch—if I tell you that years ago, having some fifty pages of what would now be fifty pages of typewriting, to copy, and several manifold copies to be made, that Mr. Edison, my brother, one other operator and myself took turns in sending and then copying down from the sounder. We did that because it is an easier way to copy it from the sounder than by looking from one page to another. You simply write and the words go in your ear and go out of your pen or pencil onto the paper and that becomes so automatic that in the course of receiving a long press report, as we did during the Civil War, the operator was obliged to take a bunch of carbon paper and change the sheets at the bottom of each page so as to pick up the work when a new batch of sheets were ready, and this involved keeping behind about fifteen words, behind the sounder, and it took all of the next page to catch up with the sender. I am giving you this as an instance of what the telegraph system really is. Now, we take the way station of a railroad and the operator always has to look out for baggage and various things around the place and wherever he is in that room, no matter whether he is called or not, he knows what is going on over the wire. Of course, if he is called, he is obliged to answer. As an instance of what an operator can pick up in that way, I went down from Great Barrington, to Sheffield, expecting to ride back on the passenger train. It was bulletined on the telegraph board " No Report ". I thought I could get to Great Barrington for dinner but I could not find out whether I could and I sat there waiting to get my lunch, growing hungrier all the time. Meanwhile I heard a message going over the line that the train had been delayed, and that they would meet at Canam somewhere below, and so on; and I figured out it would be an hour and forty minutes before the train would be along. So I went to the operator and said, " How late is your train going to be?" He says, " I don't know; I have had no report of it." I said to him, " According to the information I received, they are going to meet at Canam and it will be about an hour and forty minutes wait, and I thought I would have time to go out and get my lunch." Well, he said, " you are a pretty good guesser."

Perhaps what we may call that particular qualification of the telegraph would not appeal to the railroad management, that a man outside could find out how the trains were running. The point I am endeavoring to make in this is, that the Morse system is available to that man wherever he may be walking around the place. He has not got to go and answer a call and put a telephone up to his ear and drop everything else; but he takes that incidentally with his other work. That is simply one of the features of the Morse system that appeals to the railroad telegraph man. You must remember also that a great many of the men who are in active management are practical Morse operators, have grown up with the system, and know what it can do. This question has been discussed before several conventions of the Railway Telegraph Superintendents, and the probabilities are that I shall have occasion to discuss it at their next convention in June. So you will see that there is another side to the question. Here you have a railroad force developed from telegraph operators who are familiar with a system of this kind, and it is the simplest and best thing that appeals to us in carrying on this work. Were a sounder there, I can receive a message sitting here, and I don't have to hold anything to my ear at all. I simply sit down and write from it, and where a man has grown up with it and is familiar with it, he never can get over that love and appreciation of the simplicity of the Morse telegraph system as known to the one who has practiced it, although it is now thirty years since I have done so.

K. B. Miller: I can add my little personal touch there, although a much less skillful operator than Mr. Pope was, and having no right to claim to be an old timer, that it is much easier for me, or would have been in days gone by, to have written down matter taken from a sounder than to get it by telephone. Mr. Pope's remarks suggest a distinct need in railway train dispatching. Some way may be evolved of relieving the despatcher, who is a rather important man, from wearing a harness—I refer to the head telephone. They don't like to do it. The loud speaking receiver has been proposed and tried out rather carefully, and so far as I know has failed. One very ingenious way has been proposed and tried, but has not met with good results owing to poor articulation. It is to use at the despatcher's station a telephone repeater so that the feeble incoming currents could be magnified to produce loud talk in the receiver, and thus relieve the despatcher of the necessity of listening to a receiver held to his ear. This produced plenty of noise but it is articulate speech rather than noise that railway train despatching needs.

C. F. Elwell: In glancing over the paper, I was struck by the last paragraph, "Although the telephone has been in use on railroad divisions for less than four years, it has proven to have a great many advantages over the telegraph." I only intrude on your time to tell you the little experience I have had with the thing 10 years ago in Australia. I went out there to put in block signal systems, and they were already then using the telephone for all of their work. They had a system there in circuits of about 100 miles, just a parallel system magneto and code of signals for ringing. The signals were usually Morse letters, dots and dashes, and they seemed to have very good satisfaction with the phone. They had no telegraph instruments in the office at all. In the matter of calling up, we found lots of times that at certain stations it was almost needless to call. All we had to do was to take the phone off and say, "Are you there?" Those men used to sit with the receiver glued to their ears so they could know all that was going on between all the stations. I just mention this in passing to show you that the matter is a good deal older in other countries. I don't know how old it is there, but I know this was in 1901—ten years ago.

Ralph W. Pope: I might add to my remarks, that the conditions which I spoke of in regard to the railroad service have changed very much within my recollection. When I entered the service, the station agents knew nothing about the telegraph, so in order to have telegraph facilities, the railroad was obliged to have an operator in addition to the agent, so that today we have this different state of affairs where the telegraph operator has grown up to be the agent, and the agent therefore is not necessarily obliged to have an operator at his station, on his staff. This means nothing in large stations where they have several employees, because there is enough work to keep the operator busy; but in small stations it simply means that one man, by his knowledge of telegraphy, his knowledge of railroad work, can be the whole thing.

S. G. McMeen: Some gentleman asked the author the question whether systems of this kind could be used on telephone lines associated with transmission lines? If Mr. Lisberger is present, he can speak of a system of this kind which is in service with a transmission line and distributing system, all within one system, but which has in it all the elements which would result in a long transmission. He could give practical information on a selector line. As to the thought, the author may criticize my asking the question, in this particular case in which Mr. Lisberger is familiar, as it connects stations which he operates, the only difference between a long transmission line and his case, is in the line. It is not in the apparatus or in the operation of the apparatus. Therefore, the problem becomes this: If with the system he has he had a longer line and a greater exposure, he would have a practical answer to the question which has been answered. Now, if the lines were longer and had a greater exposure, what new difficulties would be introduced? Only these: that the greater exposure might make that line noisy if it were not well balanced. That is to say, the only features which might make it unsuccessful in that case would be line features. And if we can build a telephone line which will be quiet during reasonable perfection of the telegraph line which it accompanies, then we can have good service over it. Such lines as that are operating every day successfully. So far as the telephone line and telegraph line are in normal condition, then successful operation ensues. There is nothing in the selective apparatus or in the special features of the dispatching circuit which would cause that line to be less easily perfected and operated than a telephone bridging apparatus. Therefore I would like to hear Mr. Lisberger speak of this line as to its automatic and rapid selection, which represents everything that is of a new character as to which the gentleman asked.

Ralph W. Pope: I wish to express my appreciation especially of this telephone session. Perhaps the Institute has been criticized more severely by some of its members upon this telephone question than any other branch of electrical engineering, as to why it was not giving more attention to the telephone. As you know, that means, why have we not had more telephone papers? I think that this question has been answered—that for the first time we have had Mr. McMeen as an active member of the Telephony and Telegraphy Committee on the Pacific Coast where both great systems of telephony are in operation. We have had Col. Reber as chairman of that committee and he has taken a great deal of interest in this subject and has added to it a great deal by reason of his great familiarity with it due to the position he holds in the Signal Department of the Government.

I must admit I was surprised at the number and quality of this group of telephone papers. I think that great credit is due to Mr. McMeen for his activity in getting them together. I wish to say further that we have had telephone papers before but they never have been discussed so thoroughly by people who were familiar with the various systems in use. This meeting, suggested by Mr. McMeen, for this year, to my mind marks an epoch in the development of the Institute's treatment of telephone engineering. It will be up to us, wherever we may meet hereafter, to endeavor to attain this standard.

J. A. Lighthipe: I have been out of the telephone work a long time but I feel like our beloved Secretary, Mr. Pope, no matter how long he is away from the old original Morse, he still loves it. It is the same way with me in the telephone work. I still love it and try to follow it.

In the old days of the telephone, when it first started, the best receiver we had was what we called a crown receiver. It had six magnets screwed on the back of a handle, and was found to be wonderfully improved by dropping off five and using one. Then the only carbon buttons that were used in the country—we must give Mr. Edison the credit of being the first man who really used carbon buttons on his transmitter—were made in a small shack in the rear of the laboratory at Menlo Park. Mr. Edison could not use commercial lamp black for making the buttons so he made it by smoking kerosene lamps. He had about fifty of these lamps with a V cut out of the center of the wick to make it smoke, and kept the chimneys turning around until they were full of lampblack which was scraped out later.

The smoking process was attended to by an old Irishman who was possessed of great skill in picking up a lamp when it was on fire and throwing it out of the open door. The old transmitter was made of two brass buttons the faces of which were covered with platinum, and a carbon button pressed in between them. At that time it completely revolutionized the telephone business. It was the first time we could talk any distance at all and it really opened the commercial field for telephone work.

Mr. Edison, at that time, was quite deaf. Today he is even more so. It is very hard to talk to him. He could hardly hear the old Bell telephone; even with the carbon transmitter. It was hard work for him to understand what was said at the other end. He therefore tried to invent, or did invent a loud speaking telephone. Very few of you have ever seen one, although they are very simple to make. They consist of a chalk cylinder made by pressing precipitated chalk and afterward turning it down to one inch in diameter. Upon the surface of the cylinder rested a small stylus tipped with palladium. The end of the stylus was fastened to the center of a mica diaphragm. This cylinder was continually rotating and when the telephone was properly adjusted the sound coming out of the receiver was considerably louder than that going into the transmitter; you almost invariably had to pull your ear away when you were talking into it. I don't know that the principle of that telephone has ever been thoroughly understood. When a current passes through the stylus to the cylinder, the tension is released. In turning the cylinder the diaphragm was continually pulled in one direction. As the different waves passed through the chalk the stylus would slip so that the mica diaphragm in the receiver would practically duplicate the motion of the diaphragm in the transmitter. This telephone lasted only a few months. I don't think it was ever introduced in this country. They tried to put it in use in London, but today it is simply laid aside as one of our curiosities.

When the Blake transmitter came out, it was the starting point of all our telephones. It was adjusted so beautifully that you could stand off five or six inches from the transmitter, whereas before you had to talk right up close. The old Blake transmitter probably has done more good towards the universal adoption of the telephone system than any one thing.

In closing I will simply state that I am very very glad to meet the engineers of the telephone convention here. I have followed up, as far as I could, in my crude way, what wonderful improvements they have made. Mr. McMeen was kind enough to show me the first automatic machine I ever saw. That was at Fourth and Market Streets in San Francisco right after the fire. I was simply astonished at the magnificent mechanism of that machine. It was almost human in its hunting up a free trunk, selecting the number, either getting the subscriber or answering back that it was busy. I had no idea up to that time what a wonderful development had been made.

S. J. Lisberger: The telephone system which we have in use in San Francisco is not in any wise connected with a long distance transmission system. The system of the San Francisco Gas & Electric Co. is that used by most companies in city distribution work, namely, a main generating station with a number of substations. In San Francisco we have nine substations and one generating station. We were confronted with the problem of quick despatching between substations in times of trouble. Our ordinary system of telephone communication is a central board in our main office building on Sutter Street, from which point lines radiate to stations and substations. There is always an operator at this main switchboard day and night. It was therefore necessary if an operator at substation B wanted to get into communication with substation C, to get into communication with the main office first. If we lost a bank of transformers, or a small section of line came down, or in the event of serious trouble to a substation, such as we had after the San Francisco fire, there would be so many calls coming into the main board, that the operator could not give time and attention to the substation calls, and very often we found that if one substation could only get into communication with another substation the trouble could be very quickly remedied, whereas we were often delayed five or ten minutes. The solution of the problem was to get quick communication between substations. The system we finally adopted was worked out for us by Mr. McMeen and was an automatic system. We had objections to an intercommunicating system of our own due to the fact that it must be attached to our poles or in our conduits and that was open to the objection that if we had trouble it was entirely possible to lose our entire communicating system. The wire system, belongs entirely to the Home Telephone Company; is carried on their own lines, in their own conduit systems, and is entirely independent of the system we have in operation; all that is necessary for one station to get another is merely to turn the selector switch to the required numbers—it takes three different movements to call; the system starts with 721 and runs to 730. I have shown to several of our visitors the time it takes to call a station, which is about 9 seconds.

It is very often necessary for one station to talk to three stations, or four stations at a time and we have what we call a master switch and one station can get every other station on the line by working that mechanism. Mr. McMeen went further to help us in the problem, (but we did not take his further suggestion, not because we did not want it, but because we could not afford it) wherein he offered to give us a signal board which would show, by means of lights when we were calling a series of stations, whether they answered or not. If station C called stations B, E and F, under our present system, station C would ring first station B, then station E and then station F. All the stations have orders to wait on the line until someone talks. Mr. McMeen designed an indicating board that would quickly indicate who was on the line, would show when B was on the line and next E was on the line and next F was on the line. That was very nice but involved some financial difficulties that we did not care to meet. Otherwise, in all matters it is most satisfactory to us.

S. G. McMeen: I might say that although Mr. Lisberger spoke of this as automatic, it is not an adaptation of the automatic station equipment. It is an adaptation of the railway dispatching apparatus. The devices used are not telephone exchange selectors, but railway telephone selectors, although instead of working the telegraph key, the operator works it with a round, automatic station dial. This is merely used as an interruptor for the calling impulses.

Gregory Brown: Mr. Miller brought up the question of separate signalling circuits. There is one type of selector, so far as I know, that uses three wires—one for signalling and two for talking. That has not been very extensively used. When you consider the impedance of the selectors across the line, it hardly seems necessary to consider that line very heavily loaded as far as transmission is concerned. For that reason, I do not believe it would be necessary to have a separate signalling wire. Selectors are also being experimented with now that have an impedance of something over 600,000 ohms. These selectors contain advantages due to that high resistance, and if they are used, it certainly would not be necessary from a transmission standpoint to have an extra signalling wire.

Mr. Cramer seems to have had quite a few troubles. The first he mentions is that he does not find it feasible to signal and talk at the same time. I have been around pretty nearly all over the country on the various roads, and this is a complaint that is practically new to me. In some cases I have found this to occur, but on investigation we generally find that there is some trouble with the despatchers apparatus. One of the troubles that occurs perhaps more than any other and causes these results is the breaking down of the condensers at the dispatcher's office. These would not round off a sending wave to such a great extent.

The length of ring has been criticized—the length of ring at the station. I have gotten around that, where they want a longer ring, by installing a strap key at the dispatcher's office. This key is wired in a parallel with the automatic keys, and if the dispatcher, for any reason wants the bell in the station he is calling to ring longer than would ordinarily be the case, he turns the calling key of that station, and when he hears the answer back he merely presses down the strap key. There are various other modifications of selector arrangements which permit the bell to ring in the substation until the substation operator presses a button. In fact, most any kind of service can be given, according to what the particular railroad wants, but, as a general thing, most of them are satisfied with a certain length ring, about a second and a half, uniformly in all stations.

Another trouble that was experienced was that the agent sticks a toothpick or something in the push button and holds it down. The obvious plan to pursue there is to fire the agent; and this has been done in a great many cases, especially when the telephone was first used on railroads. As has been mentioned by several of the speakers, the operators bucked a good deal at the introduction of the telephone, their idea being that they probably were going to have their salaries reduced, or some of them would lose their jobs. It is not the policy of large railroads to put men out of employment except in very extreme cases, and if the introduction of the telephone permits offices to be closed, or forces to be reduced at certain points the men as a rule are taken care of in some other position.

A test on a 33,000-volt line was mentioned in which the apparatus of two manufacturers was used. It seems to me that the telephone apparatus used in this test is at least very similar among manufacturers, that is, the large manufacturers, and that it hardly could be a question of quality of apparatus to show up in the way that was indicated; that is, according to the statement that was made, I gather that one of them failed completely, and the other one gave good satisfaction. It seems to me there must have been another factor that entered into those two tests that caused that great difference, because the transmitters and coils, and so on, are very nearly similar insofar as their excellence is concerned.

Mr. Bennett spoke of calling and selecting on transmission lines. Mr. McMeen answered this question about the only way it can be answered, I guess, and that is with proper transpositions of your line if you get a quiet telephone line you can do anything with it in the way of talking and selecting.

Mr. Pope brought up the point in favor of the telegraph in that you could hear the telegraph when you were at some distance away from the instrument, whereas in the telephone you have to have the instrument up to your ear. About two months ago I conducted a trial installation down on one of the Pennsylvania lines, using a new type of loud speaking receiver. Criticism has been made of the telephone when used on a railroad division that it was all right for every purpose except blocking, and that for this purpose it was not as quick as the telegraph, and this criticism seemed to be more or less justified. The reason that this criticism was made was that in telephone blocking it is necessary for the operator to ring up another operator and then go through the motions of putting the receiver on his head and talking with him, whereas with the telegraph he merely ticks off what he wants to say and it is done. And that was the reason for the development or the experiments with loud speakers of various kinds and the attempt to develop a good one.

There has been considerable work done on this, and although it has been comparatively easy to get up a loud speaker for blocking—one that was plenty loud enough—still the articulation was not what it should be. This blocking service represents an ideal condition for loud speakers, because the lines are extremely short and are not loaded, and you can take full advantage of all the energy coming out of the transmitter. This installation was put in in three or four of the towers, and was left in for about ten days. During that time it was used exclusively by the operators for blocking trains, and in fact, they much preferred to use these speakers because the work was easier for them. They were then taken out merely to put them in in a better shape the next time as far as mounting is concerned, making it more convenient for use, and also to employ a busy test by means of a buzzer that had not been taken care of in the first installation. It is intended to use or experiment with this same type of receiver for dispatcher's use, and there will shortly be some trials in that field.

Mr. Elwell spoke of a train dispatching line being in use in Australia in 1902, I think it was. In the first part of my paper I mention two or three instances of the early installation of telephones on a train wire. All these installations used code ringing, and for that reason they were not very successful. There was too much of a load on the dispatcher. I think the first one used in this country was in 1883, which is probably before the one mentioned by Mr. Elwell.

I think there is no doubt that the telephone has proven its case on the railroad and I mention in the paper quite a few advantages of the telephone over the telegraph and I can probably mention quite a few more, and anybody who thinks of the matter can easily see that there is no question but what the telephone does have advantages over the telegraph. Mr. Miller, I believe, raised the point about the distinctness with which the intelligence could be transmitted over the telephone—that is, where train orders, important orders regarding train service in which human life is risked—the distinctness with which they could be heard. Now, in sending out orders, the various railroads have standardized, in their telegraph methods, and they have also adopted practically the same scheme when they shifted over to the telephone. In sending out an order the despatcher rings the various operators and they will come in and then he states a certain number, 31 or 23, or whatever it is, which indicates the type of order he is to give and he starts to give his order and as he gives his order he writes it down himself so as not to give the order faster than the operator can take it down. As the dispatcher writes the order when he comes to the name of a town or any figures whatever, engine numbers or anything similar, or the time, besides speaking it in the ordinary manner, he spells it out. After he has completed giving the order the operators in their turn repeat this back to him and as each operator repeats it back to him the despatcher underlines the word repeated, so if there are three operators repeating the record of the order would be in the desptacher's book—it would have three underlines under each word which was repeated, which would supposedly prove it had been repeated by three operators.

A paper presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 27, 1911.

CONTINUITY OF SERVICE IN TRANSMISSION SYSTEMS.

BY MAGNUS T. CRAWFORD

INTRODUCTORY STATEMENT

The object of this paper is to give the results of a number of years of operation of the Snoqualmie Falls Transmission system of the Seattle-Tacoma Power Company and to deduce therefrom practical conclusions as to the effectiveness of the method of operation used. The discussion will be confined entirely to the transmission system, and the possibilities of insuring continuous service by means of auxiliary steam plants will not be considered. Each high-tension system is a problem in itself and must be worked out with respect to its individual features and conditions, such as generating capacity in kilowatts, length of lines, size of wires, ratio of resistance and reactance, line voltage and climatic conditions. It is believed however, that a log of the operating results of a particular system is worthy of record, if the conditions of operation are correctly described.

DESCRIPTIVE DATA

The general features of the system are shown in the accompanying diagram and illustrations.

A good description of the original installation as completed in 1900 may be found in *Engineering News*, December 13, 1900, and the evolution of the transmission line was described in a paper read before the Seattle Section of the A.I.E.E., December 19, 1908, published in the PROCEEDINGS, and in the Journal of Electricity, April 24, 1909. This paper covers only the four years 1907, 1908, 1909 and 1910.

Generator capacity 12000 kw., step-up transformers 15,000 kw. Transmission 30,000 volts three-phase, neutral ungrounded.

Poles. Cedar, average height 40 to 50 feet. (12.19 to 15.24 m.).

Spans. 135 to 160 ft. (41.14 to 48.76 m.) average length; up to 1000 ft. (304.8 m.) at river crossings.

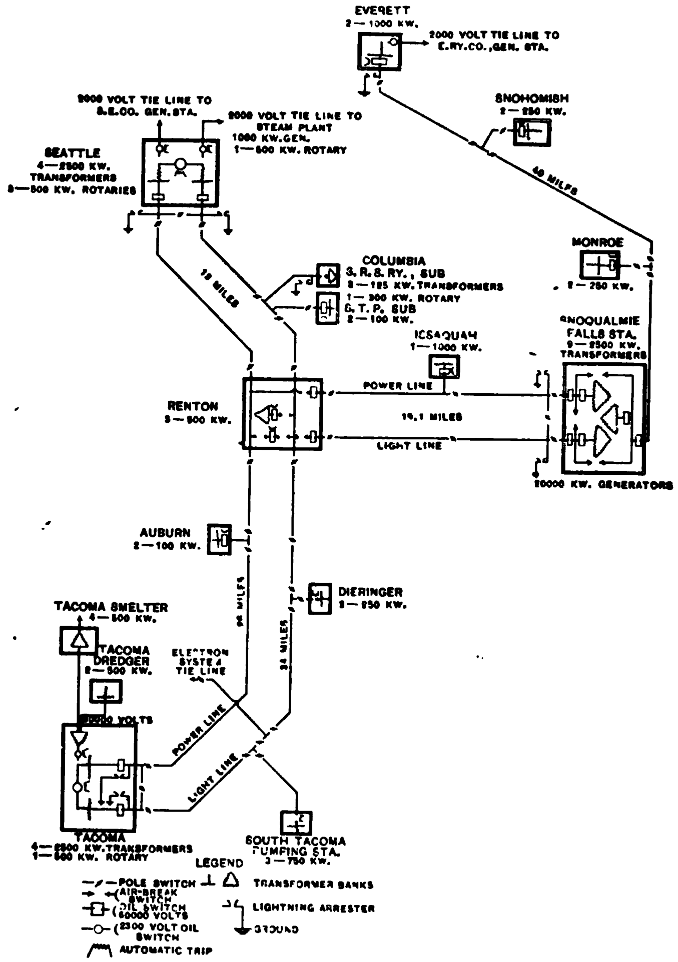


Diagram of 60,000-volt transmission system.

Lines. Falls to Renton 20 miles (32.18 km.) two pole lines. Renton to Seattle 13 miles (20.92 km.), two pole lines. Renton to Tacoma 26 miles (41.84 km.) by one pole line and 34 miles (54.71 km.) by the other. Falls to Everett 40 miles (64.37 km.) one pole line. Tacoma to Smelter at Point Defiance, 6 miles (9.65 km.) one pole line. Total 172 miles (276.8 km.)

Wires. Falls to Renton No. 4/0 seven-strand aluminum. Renton to Seattle and Tacoma, No. 2/0 seven-strand aluminum. Falls to Everett, No. 4 solid copper. Tacoma to Smelter, No. 4 solid copper.

Spacing. 7 by 9 ft. (2.13 by 2.74 m.) and 7 ft. (2.13 m.) equilateral triangles.

Insulators. One piece, tripple petticoat porcelain, 6 in. (15.24 cm.) diameter, Redlands pattern. White imperial porcelain on main lines. Brown porcelain on Everett line, not tested before installation.

Pins. Locust wood, impregnated with paraffine.

Cross Arms. Four by 5½ in. (10.1 by 11.13 cm.) to 5 by 6 in. (12.7 by 15.24 cm.) select Washington fir.

Switches. At Falls, non-automatic remote control, vertical break oil switches in brick compartments. At Renton, Seattle and Tacoma, non-automatic lever control. rotating horizontal break oil switches in iron tanks. At small stations and for throwing lines in multiple, fused air break "jack" switches or fused horn switches.

Protective Apparatus. Multigap lightning arresters with series resistances.

1908

Wood pins changed to malleable iron on corners and important points

1909

Transmission voltage raised to 60,000 volts on December 6, 1909, using same, wires, poles and cross arms.

Insulators. Four-piece brown porcelain of standard design, each tested to 120,000 volts, and made with threaded 1½-in. (38.1 mm.) pin hole.

Pins. Malleable cast iron with threaded head.

Switches. At Falls and Renton, non-automatic remote control, vertical-break oil switches in steel tanks. At Seattle, Tacoma and Everett, non-automatic lever control rotating horizontal-break oil switches in iron tanks. At small substations, series trip coil actuated automatic overload release, rotating horizontal break oil circuit-breakers in iron tanks.

Disconnecting Switches. Out-door pole top type, three-pole double break, consisting of contact jaws mounted on line insulators with connecting blades rotating in a horizontal plane.

Protective Apparatus. Aluminum cell electrolytic lightning arresters installed at each end of each line.

1910

Additional 8750 kw. generator put in service in November, with 8750 kw. additional step-up transformer capacity.

Outline of System of Operation

In the operation of high-voltage lines on the Snoqualmie system the high-voltage line switches are non-automatic electrically-operated by remote control except those used in throwing the lines in multiple at substations, which are instantaneous overload release switches. The Falls operator has on his switchboard an indicating ammeter and the control handle for an electrically-operated remote-control oil switch for each outgoing high-voltage line.

The generator oil switches are kept blocked in solid on the bus bars except when synchronizing a new machine. If the Snoqualmie system is running in parallel with the Electron system or with other generating systems as is frequently the case, the connection is made with instantaneous overload-release circuit-breakers, and a similar connection is made with the steam plant at Seattle.

When a short circuit comes on the system all automatic circuit breakers connecting other systems and all switches for multiple connections drop out at once, leaving each line separate clear to the Falls. The Falls operator first lowers the voltage and gets the speed of the machinery under control. It is then usually apparent on the line ammeters which line is short circuited, and if it does not burn clear in a few seconds it is opened with the remote-control oil switch. The voltage is then slowly brought back to normal and only a part of the load is lost. The substation operators then open their end of their line at the pole switch, and linemen are sent out to the defective section of the line. This is located by opening all pole switches in the line and then testing out one section at a time, starting at the Falls, until a section is found which shows trouble.

If it is not apparent to the Falls operator which line is in trouble, the short circuit is fed thirty seconds, and one of the lines opened, and if it still does not clear it is fed thirty seconds longer on the other line, and the station is never shut down as long as it can be kept running. Two large water rheostats of iron wire immersed in the tailrace and provided with oil switches are thrown on the generator bus whenever a heavy load is to be dropped, as in opening a short circuited line, and serve to aid the control of speed and voltage. In extreme cases where trouble holds and all lines are opened, the station is run on the water rheostats and each line thrown in again at intervals until one is found that is clear.

Substation operators open all high-tension switches when power goes off the line and immediately make connections with another generating system or steam plant, and pick up the local load until power comes on the lines again.

The details of the system of upkeep employed in connection with the transmission system have been carefully worked out, as a great many of the interruptions in service may be avoided by proper maintenance of the lines. Eight patrolmen are employed and each held responsible for the condition of a part of the line. They are stationed at a transforming station as near as possible to the middle of their patrol, and furnished with a residence and a telephone from the private line. Patrolmen are furnished with a saddle horse and saddle bag containing telephone test set, sundry tools and material, and once each week they carefully inspect their section of the line. All badly broken insulators are replaced and any other necessary repairs made. Every two miles along the line a small booth is fastened to a pole, and a stock of insulators, pins, cross arms, line wire, etc., are kept locked up therein, so that in case of trouble, material for repairs will always be within one mile.

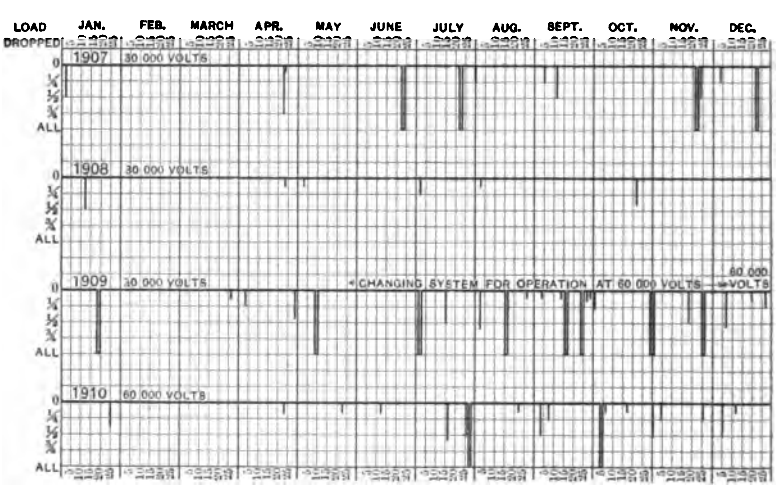
Each patrolman also has charge of the pole switches in his territory and once a month he makes a complete and thorough examination of each switch, keeping the parts well oiled and in perfect alignment. Each week he makes a written report on a printed form of the results of his line patrol and switch examination.

When any repair work is to be done on a high-tension line, it is killed and opened by an air-break switch at each end, and the lineman working on the line makes a solid short circuit and ground at the point where he is working, with a flexible cable provided for the purpose. All lines are in charge of the station operator, and linemen notify the operator by telephone when a line is desired, waiting until he is told the line is dead before doing any work thereon. All communications between employees in connection with high voltage are repeated back to the speaker, and are written down in the station log book. These precautions are necessary to reduce mistakes to a minimum.

EXPLANATION OF TABLES

The following tables and curves show a log of the operation of the transmission system for the last four years. All cases of trouble on the high-tension lines or in transformers that caused an appreciable disturbance of the line voltage are recorded, but short circuits on low-tension distribution systems and other troubles not chargeable to the transmission system are excluded. The times given as " shut down " are cases where power was off the high tension lines of the Snoqualmie system long enough to switch out the defective line. The actual service interruptions were of very short duration, as power was usually obtained immediately from another system or steam plant at Seattle, Tacoma and Everett.

The conditions of transmission are somewhat severe, as the lines pass through rough country and along country roads. The land is being cleared for agricultural purposes and for new railroads, so that a great deal of blasting and grading is being carried on, causing much trouble. The pole line has been built ten years, and has not the mechanical factor of safety of a new line. The tables show how the troubles resulting from these adverse conditions were handled with a minimum disturbance to service, as out of the total of 66 cases of trouble given in the table, 52, or about 80 per cent, were handled without an interruption of service.



Service interruptions on the Snoqualmie transmission system

During the latter part of 1907 considerable trouble was caused by burned wooden pins. These pins had been in service nearly seven years, and the threaded tops were softened to pulp, apparently by the action of nitric acid formed from the air and moisture by the leakage currents.

The line was gone over by patrolmen and on all turns and important places the wood pins were replaced by malleable iron pins, and no more trouble resulted from this cause. With the weak points thus fixed the system gave practically continuous service during the year 1908. During 1909 the work of reconstruction for 60,000 volts was in progress and nearly half of the system was cut out during working hours for work thereon, and the switching was in a temporary condition at many places. These circumstances made it difficult to handle trouble without interruption of service. During the year since the change to 60,000 volts there have been only two shut-downs out of 23 cases of trouble, showing the method of operation is equally successful at the increased voltage.

The duplicate high voltage lines are known by the names light and power lines respectively, and are divided into sections known by the names of the principal stations toward which they lead from the junction point at Renton.

TABLE I

SERVICE INTERRUPTIONS

Date	Extent	Load dropped	Remarks
1907 Jan. 2 9:55 p.m.	Short voltage dip	About half	Snow on outlets at transformer house at Falls makes short circuit on power line by starting an arc. Falls operator opened power line and cleared trouble, throwing on water rheostats until load returned.
Jan. 3 1:10 a.m.	Short voltage dip	None	Short circuit on light line, burned clear. Cause unknown.
April 23 4:15 p.m.	Prolonged voltage dip	Nearly all	Telephone wires blown into high-tension wires near Seattle by high wind. Burned clear.
April 24 6:04 p.m.	Four seconds voltage dip	Small	Short circuit on system, cause unknown. Burned clear.
June 24 2:15 p.m.	Shut down	All	Solid short circuit on both lines holds until lines are opened. Cause unknown. No trouble found when lines are put in again.
July 23 8:30 p.m.	Shut down	All	Piece of iron wire thrown over both lines near Tacoma. Falls operator pulled the short circuit 30 seconds on each line before shutting down, but unable to burn clear.
August 1 7:50 p.m.	Eight seconds voltage dip	One-fourth	Arc started by lightning between wires at outlets in Seattle substation. Burned clear by lowering voltage.
Sept. 5 1:15 p.m.	Dip in voltage	One-fourth	Severe short circuit comes on light line but is burned clear. Cause unknown.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Sept. 11 12:45 p.m.	Dip in voltage	Nearly half	Lightning storm between Renton and Tacoma. Short circuit appears on both lines but burns itself clear.
Oct. 16 10:00 a.m.	Small voltage dip	Small	Light short circuit on power line is burned clear. Caused by limb from burning tree between Auburn and Tacoma.
1907 Nov. 22 2:45 p.m.	Shut down	All	Wooden insulator pins burned off on corner pole between Renton and Kent causing short circuit and ground on light line. Arcing ground burns up nearly two spans of wire at point of break. Surges burn up multi gap lightning arresters in stations and cause pins to burn off at other points on lines where insulators were defective.
Nov. 23 5-6 p.m.	Frequent successive voltage dips	About half	Trouble develops from burned insulator pins at different points probably at places where insulators were cracked by surging ground of Nov. 22. Pole near Everett was set on fire and Everett line was out until repaired. One wire of light line in Seattle burned off cross arm and came across 13,000-volt lead of S. E. Co. As Seattle power line was cut out for repairs at other points, Seattle was out eight minutes. One transformer punctured at Seattle. Falls line also down from burned off pins near Renton but cut out before causing damage, and repairs made.
Dec. 4 3:30 p.m.	Six second dip	One-fourth	Short circuit appeared on light line and is burned clear. Low tension wires get tangled up on pole in Auburn and one of them swings up over high-tension line and is burned off. Caused by high winds.
Dec. 23 4.00 p.m.	Shut down	All	Heavy wind storm blows limb of tree into light line near Issaquah, blows down power line near Kent and light line near Auburn, all at same time Last two places were where pins were nearly burnt off. Falls operator lowered voltage and stayed in on each line separately for 60 seconds, but was unable to clear trouble. Station ran on water rheostats until troubles were located and one line repaired through.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
1908 Jan. 12 5:00 p.m.	Voltage dip	About half	Short circuit on branch line to smelter in Tacoma. High-tension fuses in Tacoma substation did not open and short circuit was pulled 30 seconds by Falls operator and burned clear. Cause unknown.
April 24 3:50 a.m.	Ten seconds voltage dip	Small	Tree blown into Falls light line one-half mile (0.8 km.) from Renton. Light line opened and trouble cleared.
April 24 4:20 a.m.	Short voltage dip	Small	Everett line down near Snohomish due to defective insulators. Everett line opened and trouble cleared.
May 2 1:50 p.m.	Short voltage dip	Small	Defective insulators on line to Tacoma lets wires down on cross arm. Cross arm burned off, clearing trouble.
July 2 3:15 p.m.	Ten second voltage dip	One-fourth	Short circuit and ground on power line due to defective pole switch at Seattle. Seattle operator knew location of trouble and cleared it by opening high-tension line oil switch.
August 3 9:45 p.m.	Short voltage dip	Small	500 kw. transformer burned out at Lewis & Wiley' pumping station. Cleared by high-tension fuse in substation.
Oct. 22 4:32 a.m.	Voltage dip	Nearly half	Short circuit on line to dredger in Tacoma harbor cleared by high-tension fuse. Caused by salt water fog where line runs about 30 ft. (9.14 m.) from surface of water, and spacing between wires only 3½ ft. (8.9 cm.)
1909 Jan. 3 8:10 p.m.	Short voltage dip	Small	Short circuit on Tacoma dredger line. Cleared by high-tension fuses. Caused by salt fog.
Jan. 19 2:30 p.m.	Shut down	All	Line to Tacoma smelter was connected to both light and power lines at Tacoma substation when a land slide carried away several spans. Falls operator lowered voltage and kept each line in 30 seconds before opening.
March 26 5:00 a.m.	Short voltage dip	Small	500-kw. transformer burned out at Lewis & Wiley pumping plant. Cleared by high-tension fuse in substation.
April 4 8:45 p.m.	Long voltage dip	One-fourth	Severe short circuit on Tacoma dredger line holds until voltage is lowered. Probably from salt fog.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
April 29 8:20 a.m.	Voltage dip	Nearly half	Transformer burned out and grounded on Tacoma smelter line. Discharges lightning arresters in Seattle and Tacoma substations.
May 10 11:25 a.m.	Shut down	All	Burning tree falls into Tacoma power line near Auburn, breaking down four spans of line, causing arcing ground that results in puncture of No. 1 generator armature. Lines opened until defective generator could be cut out and load picked up on rest of station.
July 2 5:15 p.m.	Shut down	All	While Tacoma power line was cut out for work thereon, light line was connected to both Falls lines and a tree was blown into the light line near Auburn, making a short circuit and ground which would not burn clear. Both lines had to be opened until defective line could be switched out at Renton.
July 3 12:35 a.m.	Heavy voltage dip	Small	Short circuit on power line burned clear. Linemen repairing break of July 2nd on a dark night left telephone wire across line, and when line is switched in at Renton telephone wire is fused.
July 15 10:30 a.m.	Voltage dip	Half	Short circuit on light line near Seattle, cause unknown. Light line opened, clearing trouble.
August 2 12:15 p.m.	Sixty seconds voltage dip	Over half	Falls line cut out for linemen to work on about 3 miles (4.8 km.) from Renton. A solid short circuit and ground put on wires where they were working with a piece of ¼-in. (6.35 mm.) steel mast arm rope, as a safety precaution. By mistake line was reported clear and switched in at Renton end with short circuit still on and Renton multiple switch closed solid. Falls operator lowered voltage and pulled the short circuit by way of light line and Renton multiple switch. In about 60 seconds the ¼-in. (6.35-mm.) steel rope was fused clear of the line, and water rheostats were thrown on generator bus.
August 16 5:20 p.m.	Shut down	All	Steam shovel gets into line at Seattle, letting down two spans and causing arcing ground and short circuit that punctures two transformers and No. 5 generator at Falls. Station shut down until defective apparatus could be cut out.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
August 26 2:50 p.m.	Short voltage dip	Small	Short circuit in 500-kw. transformer at Lewis & Wiley's pumping plant. Cleared by high-tension fuse in substation.
Sept. 4 2:35 p.m.	Voltage dip	Everett only	Short circuit on Everett line cause unknown. Cleared by high-tension fuse on Everett line.
Sept. 13 12:15 p.m.	Voltage dip	Everett only	Short circuit on Everett line caused by blasting stump into line. Cleared by fuses on Everett line.
Sept. 16 3:20 p.m.	Shut down	All	Seattle light line short circuit and grounded by blasting stumps near Seattle. Arcing ground punctures No. 3 generator armature and station is shut down.
Sept. 24 7:00 p.m.	Shut down	All	Pile driver knocks down long span in Everett line across Snohomish River. Fuses blow on Everett line and start arc across wires short circuiting high tension bus in transformer house at Falls; station shut down until bus could be cleared.
Sept. 26 7:12 p.m.	Voltage dip	Everett only	Short circuit on Everett line cleared by fuses. Pile driver strikes line at Snohomish.
Sept. 27 2:40 p.m.	Voltage dip	Small	Pole switch at Puyallup does not close properly and starts arc across wires when opened. Burned clear by lowering voltage.
Sept. 30 8:05 p.m.	Heavy voltage dip	One-fourth	800-kw. transformer burned out at South Tacoma pumping station. Cleared by fuses in substation.
Oct. 31 10:35 a.m.	Shut down	All	Light line cut out for work thereon when power line was torn down by blasting stumps near Kent. Falls operator was unable to burn the trouble off and cut both lines out until Renton switched clear of the trouble.
Nov. 18 1:30 p.m.	No shut-down of system	Half	Floods and high winds washed out 12 poles carrying both light and power lines near Tacoma, and they were blown over. Trouble reported and lines opened before they went down Wires not broken and poles were pulled up clear of the ground and lines cut in

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Nov. 25 9:00 a.m.	Shut down	All	Flood washes out Everett line near Snohomish. Wires and switching in temporary condition at Falls during change to 60,000 volts, and unable to clear without shut down.
Dec. 5			SYSTEM CHANGED FROM 30,000 TO 60,000 VOLTS WITHOUT INTERRUPTION OF SERVICE.
Dec. 6 10:28 p.m.	Heavy voltage dip	Over half	Limb ot tree blown into light line 2½ miles (4 km.) from Falls breaking wires and causing short circuit and arcing ground Electrolytic lightning arresters discharged taking heavy surges off of line. Light line opened by operator clearing trouble; water rheostats thrown on until load returned.
Dec. 20 10:15 a.m.	Voltage dip	Small	Pole switch arced across at Renton when opening Tacoma light line. Switch closed again and dip of voltage breaks arc.
Dec. 27 3:10 p.m.	Heavy voltage dip	One-fourth	Short circuit on Everett line cleared by opening line switch at Falls. Caused by blasting stump into line a few miles from the Falls, breaking wires.
Jan. 25 8:07 p.m.	Voltage dip	Nearly half	Severe short circuit cleared by opening light line. Multiple switches at Seattle and Tacoma drop out. Trouble caused by high wind blowing over a corner pole near Kent, the line falling into a lead of telephone wires. Telephone system damaged but slightly.
April 16 12:25 p.m.	Slight voltage dip and swinging of ground detector	None	Ground appears on system but burns clear in a few seconds. Caused by blasting stumps 300 ft. (91.44 m.) from line near Milton. Large rock breaks one wire of line and it falls to ground burning off clear at Falls end. Trouble located and line cut out and repaired.
April 24 9:05 a.m.	Voltage dip	Small	Pole switch on Tacoma light line arced across at Renton when opening charging current of line with blades set too close. Cleared by openign light line at Falls.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
May 23 8:15 p.m.	Voltage dip	Small	Light short circuit burns clear at once. Tree fell across light line near Renton but did not break wires. Renton operator notified of trouble and opens line at Renton.
June 12 11:35 p.m.	Slight voltage dip	Small	Surge appears on light line and ground detector, clearing immediately. Transformers at South Tacoma pumping station burned out. Trouble cleared by high-tension fuse in substation. This substation owned and operated by consumer.
July 16 9:15 a.m.	Prolonged voltage dip	Over half	Pole switch at Renton arced across when opening charging current of line with blades set too close. Short circuit appears on both lines and Falls operator opened light line. As this did not clear trouble, light line was closed again and power line opened clearing trouble.
July 26 8:10 a.m.	Heavy voltage dip	Half	Short circuit appears on Everett line and is burned clear. Cause unknown.
July 26 9:45 a.m.	Shut down	All	Tree blew across Everett line breaking wires down. Remote control handles for line switches were in a temporary location at one side of switchboard while some new panels were being put into position. Operator made mistake in switching and had to open all lines and throw on rheostats until generators could be controlled.
August 22 1:35 p.m.	Slight voltage dip	Small	Ground appears on light line, discharging electrolytic lightning arresters. Burns itself clear. Cause unknown.
August 26 6:35 p.m.	Slight voltage dip	None	Ground develops and clears itself. Cause unknown.
Sept. 3 11:15 a.m.	Voltage dip	Half	Telephone wires pulled across power line in Seattle by careless lineman. Power line opened by operator and trouble cleared. Half of load dropped as Tacoma was running on power line with light line cut out temporarily.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Sept. 7 11:05 a.m.	Voltage dip	One-fourth	Short circuit on Everett line from unknown cause. Trouble clears when Everett line is cleared.
Oct. 4 11:25 p.m.	Shut down	All	Corner pole cut down with an axe near Tacoma, both light and power lines falling across county road and telephone lead. Falls operator unable to burn clear and both lines left out until defective section could be opened. Telephone Company's system not damaged severely.
Oct. 5 11:15 a.m.	Voltage dip	Small	Short circuit on light line burns itself clear. Cause unknown.
Oct. 17 3:15 a.m.	Voltage dip	Small	Short circuit cleared by opening Everett line. Stump blasted into line by contractor building new railroad near line.
Oct. 30 11:03 a.m.	Heavy voltage dip	Over half	Short circuit appears on both lines but burns itself clear. Cause unknown.
Nov. 4 5:40 p.m.	Two successive voltage dips	One-fourth	Stump blasted into Everett line. Trouble burned clear.
Nov. 25 8:05 p.m.	Voltage dip	One-fourth	Short circuit appears and is burned clear in a few seconds. Caused by blasting piece of stump into Everett line.
Dec. 5 7:00 p.m.	Three severe voltage dips	Half	Malicious persons, throw piece of half-inch (12.7 mm.) steel cable over both light and power lines about three miles (4.82 km.) from Renton on Seattle lines. Steel cable was burned in two and trouble cleared on power line although line wires were badly scarred. On light line one line wire was burned in two, fell to ground and burned off clear of ground on Falls side. Falls operator did not open any lines, as short circuit appeared the same on each and was burned clear.
Dec. 11 12:15 a.m.	Voltage dip	Small	Defective insulator on pole switch at Seattle punctures and starts arc to ground. Electrolytic lightning arresters flash over, taking surge to ground and trouble burns itself clear.

TABLE II

SUMMARY OF SERVICE INTERRUPTIONS 1907-8-9-10

	Shut downs	Voltage dips		Total cases
		Dropping half load	Dropping one-fourth load	
1. Defective line construction, failure of switches, insulators, etc......	1	2	7	10
2. Failure in transformers............	0	1	5	6
3. Malicious interference, blasting stumps, etc.....................	6	1	7	14
4. Winds, fires, floods, fogs, etc......	6	6	6	18
5. Lightning........................	0	1	1	2
6. Mistakes by employees............	0	2	1	3
7. Unknown........................	1	4	8	13
Totals..........................	14	17	35	66

NOTE.—Of the fourteen cases of shut down, seven occurred during the half of 1909 when the system was running on one line during working hours to permit reconstruction for 60,000 volts. During the other 3½ years the average was two cases of shut down per year.

DISCUSSION OF RESULTS

Before discussing the above results, a definition of continuous service is necessary. In cases where only a voltage dip is shown, the bus voltage of 115 volts dipped down to some value between 40 and 90 volts for a few seconds and then returned to normal. To the lighting consumer this is not objectionable if it does not occur too frequently. To the small power consumer, such as shops and industries using motors in small units, generally speaking it is not a serious inconvenience, as the motors will often come back up to speed and will at most only require restarting. In the case of very large power units, they will usually stay in on the line unless they are heavily loaded or the dip is too prolonged.

The 500-kw. synchronous converters on the system almost always stay in and are not cut off until the current goes clear off the line. On the other hand if the voltage dip is very sudden in its return to normal, as where a short circuit is opened at its maximum and a Tirrill regulator has held up the generator voltage, large synchronous machines are much more apt to be thrown out. In the above table there are 52 cases where the voltage dipped but the system was not shut down, and in only 17 of these cases was the dip sufficiently prolonged to lose any considerable amount of load. In the other cases practically all the large motors stayed on the line. It seems reasonable then to conclude that moderate voltage dips of short duration do not constitute an interruption worth considering.

In cases where the voltage gets to a very low value and does not return to normal for ten seconds or more, the most of the power load will be dropped, but the lighting load will be returned. The power consumer is then put to the inconvenience of stopping work long enough to start up his motors again. The railway station operator must synchronize his converting units again, but if the drip is not over thirty seconds they should still have considerable speed and this should only be a few minutes work, which is not a hardship to railway service. Some power installations will suffer great inconvenience, such as for instance an ammonia compressing outfit, and also some electrolytic processes, where even a momentary shut down will cause heavy loss. However, such consumers will only form a small percentage of the average power company's business, and any expensive equipment to insure them absolutely continuous service should be a part of their own installation.

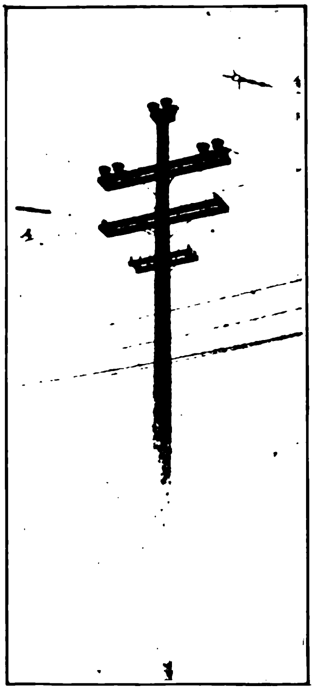
Porcelain insulator and iron pin used on 30,000-volt line

In cases where power goes completely off, all load is dropped and all consumers suffer maximum of inconvenience until service is resumed. The gross income of the power company practically ceases and the operating expenses continue, besides the loss in good will which can not be measured. If service is resumed within five minutes, the average consumer will not suffer serious loss, but where the shut down extends over thirty minutes or an hour the financial loss and inconvenience is very considerable to all parties concerned. We may then conclude that prolonged voltage dips are an inconvenience but if of infrequent occurrence are not serious menaces to satisfactory service, whereas complete shut-downs cause heavy loss. Speaking from the average consumers viewpoint, commercially continuous service may include infrequent voltage dips and very rare shut-downs of periods never exceeding five minutes.

Causes of Troubles. The first two causes in Table II are defective construction and apparatus, and burn-outs of machinery. By testing all line insulators for a voltage a little over twice normal and carefully testing all machinery winding before installation the entire system may be made to withstand double normal voltage for several minutes without failure of insulation. This means that transient voltages considerably in excess of double normal voltage can be withstood, as brought out by Steinmetz and Hayden in a paper before the A.I.E.E. in June, 1910. By installing protective apparatus such as air relief gaps which are set to break down at double voltage and which have a time lag much lower than that of the insulation of the

30,000-volt entrance construction

system, practically all destructive surges can be taken off the system. This may be done by installing electrolytic lightning arresters at the entrance to all important stations. If lightning becomes so troublesome as to shatter insulators on the line where it strikes at some distance from an arrester, relief gaps may be installed at each insulator if necessary, by means of arcing rings as described by Nicholson in a paper before the A.I.E.E., March 30, 1910. In this plant, however, lightning strokes on the line are very rare, and by using wood poles and cross arms, an entire pole may be burned down without interrupting service if the wires are not broken. The first two causes of trouble and also the sixth can thus be reduced to a minimum by properly testing the insulation of apparatus and the installation of protective apparatus.



Pole-top construction at square turns. (60,000 volts)

Pole-top construction where two lines are on the same pole, showing guard wires over railroad. (60,000 volts)

Blasting stumps is a source of much annoyance in this section of the country, and can best be handled by a campaign of publicity. The patrolman on each section of the line should make it his business to become personally acquainted with all the ranchers enroute and keep his eye open for all evidences of preparation for clearing land, and when he sees blasting is to be done call attention to the notices of warning kept on each pole, and show every desire to coöperate with the parties concerned and have the line killed before blasting is done. Deliberate interference should be prosecuted vigorously by arrest and fine where possible.

Pole-top construction on main lines. (60,000 volts)

Entrance tubes at substations. (60,000 volts)

Troubles from winds, fires, floods, etc., can be mitigated by using a very large factor of safety in the mechanical construction of the line, and by putting the high tension wires at a good height above all telephone and other wires easily broken. Structures in soft soil should be set solidly in rock boxes and well braced, lines taken via separate routes whenever possible, and always on separate pole lines. All large trees that can blow into the line should be bought and cut down, and the brush kept closely cut on the right of way.

Mistakes of employees can be reduced by providing them with definite written instructions on their duties and course of action under various conditions and by providing them with the best working equipment. Station operators in a plant employing non-automatic operation are very important units in the system; a little welfare work and good pay to good men, and in fact anything that will make them take interest in their work and pride in good results will prove an excellent investment.

Results of Method of Operation. The standard practice in the operation of duplicate transmission lines is to install automatic overload relays and circuit breakers on each line at the generating station, and reverse current relays with automatic circuit breakers at the substation. Even with complicated systems this idea may be carried out so that theoretically a short circuit anywhere on the system will automatically be cleared and the defective line cut out. The experience of this company has

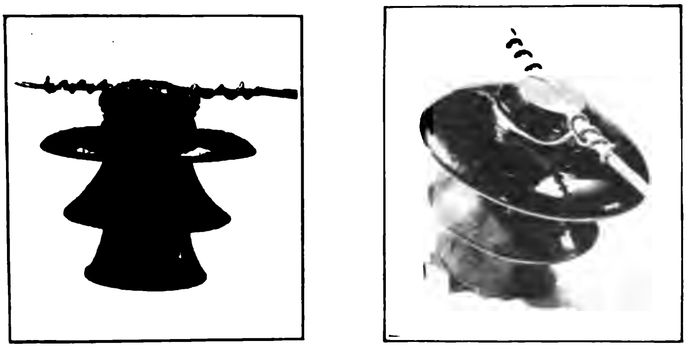
Malleable cast iron pins. Cross-arm pin fits 1½-in. hole in old crossarms. T-headed bolt slips into a seat on a shoulder cast on inside of shank at bottom, and is tightened up under cross-arm. Weights 3¾ and 7 lb. Ultimate strength 1800 lb. at line wire. (60,000 volts)

Standard pole switch. (60,000 volts)

been that practically better results can be obtained by placing the control of the high-tension lines in the hands of a carefully trained operator. From the operation of this system it is believed that the non-automatic method of operation is less apt to produce destructive oscillations when a short circuit is being cleared from the system. Taking for instance a case where a piece of iron wire is thrown across the line. There being no automatic regulation except slowly acting water wheel governors, the speed and voltage of the generating units dip severely. The operator encourages this and blocks the action of the governors, feeding the short circuit at the reduced voltage. The low-frequency high-power surge first set up by the short circuit may thus be reduced in intensity, being also dissipated by the resistance and cushioned by the reactance of the line, and the station is then simply running on a severe overload for a few seconds. If it is apparent which line is short circuited, it may then be opened with safety. If on the other hand the voltage and speed are automatically held up as far as possible by Tirrill regulators and governors, and the surge is ruptured at a point other than zero in the wave, a destructive potential will result which may cause damage.

Switching and lightning arresters at Snoqualmie Falls

In the case of an arcing ground a more severe condition exists than in a short circuit, as in cases where one line wire is whipping around on the ground, making and breaking contact. In this system where the neutral is ungrounded severely unbalanced strains may be produced in this way, as is shown by the puncturing of generator and transformer windings in such cases. An arcing ground was not always visible on the line ammeter, and an electrostatic ground detector was installed on the generating bus. This indicates promptly all high-tension grounds, and the telephone circuit along the same poles is an instantaneous indicator showing which line is grounded. Grounded lines are cut out without attempting to burn clear, and the installation of electrolytic arresters on the lines, transformers with reinforced insulation on the end coils and static relief gaps on the generating bus bars has given entire freedom from trouble from arcing grounds, as shown by the absence of failures of insulation since the installation of the new equipment in 1909.



Showing type of tie used and 60,000-volt insulator. 4/0 seven-strand aluminum cable with No. 2 tie wire

Since the change to 60,000 volts it has been the practice to open the defective line if it does not burn clear in about five to eight seconds instead of holding for thirty seconds. By the installation of a Tirrill regulator with a special relay for lowering the voltage during a short circuit the operator does not have to look after the voltage, and with accurately reading dead-beat line ammeters he is able to see the situation inside of five seconds. This equipment has been recently installed. The switches for multiple connections now installed on the low-tension side at substations work instantly instead of in the slow uncertain manner of the old 30,000-volt fuses used for this purpose, so that much better performance can be expected in handling short circuits in the future.

This method of operation is applicable to a system of several generating stations, by giving each generating station a certain amount of transmission system, and then using instantaneous automatic circuit breakers at the point of connection. These circuit breakers can be set to carry the full value of interchange current so that the plants can be operated in parallel and with any desired sharing of load; but when a short circuit comes on the line, that line and its generating station will immediately be separated from the rest of the system and can clear its own trouble. Mr. Downing's paper before the San Francisco meeting in May, 1910 on the " High Tension Network of a General Power System " describes a system operated in this way.

It is apparent from this paper that there are a number of features which an engineer could employ in building a new line that would prevent many interruptions, such as stringing the lines at a greater height and supporting them on strong structures along private right-of-way, to avoid interference. The desirability of continuous service depends on the character of the power business served, and a balance may be struck at a point where further investment to secure greater reliability may not be warranted.

DISCUSSION ON "CONTINUITY OF SERVICE IN TRANSMISSION SYSTEMS." LOS ANGELES, CAL., APRIL 27, 1911.

R. J. C. Wood: The first thing that attracted my attention was that the substation in which the line ended was solidly connected. It might be that interruptions could be made still shorter if each substation could be connected onto either end of the light or power lines, unless of course, the steam plants which the author mentions as being on the other end of the line, are kept in operation at all times, ready to pick up the load.

It is stated that an open short circuit taking place on the line is opened in a few seconds if it does not clear itself. This would seem to allow the possibility of burning the line in two. The more general practice, I believe, among the companies here is to drop the voltage as soon as possible and clear the short circuit.

It would also seem that the method of cutting in on the line every 30 sec. might be very severe on the generators and transformers.

With reference to the number of patrolmen, it states there are eight patrolmen and there are 106 miles of territory covered. That is not counting the lines twice over, for there is a double length of about 164 miles. I would like to ask the author if each man works by himself or both together. If each man works by himself it would mean he only had about 20 miles to look after.

There are several references in the latter portion of the paper in regard to electrolytic lightning arresters, and it would be interesting to know if they have met with universal success.

Reverting to the matter of testing lines to find out which section is in trouble, I would like to know whether the author plugs the line right in on the bus, or whether he separates the generator bus and then tests the thing out easily, bringing it up from a local tension.

I didn't notice any reference to the size of insulators. They look to me like 14-in. insulators.

P. M. Downing: It is very gratifying to have a paper of this kind presented and have someone come forward with data giving the number of interruptions that have occurred on a system of this kind to be honest enough to give the cause of the interruptions.

I note in the data given that but few, if any of the failures, are attributed to poles or crossarms burning as a result of leakage over the insulators. I infer that a majority of these failures are the result of lightning discharges or from high voltage disturbances. Whether or not any part of them could have been prevented by the use of electrolytic lightning arresters is a matter of conjecture. To one having to do with the operation of long high voltage lines this arrester is a very interesting piece of apparatus. On the system with which I am connected we have never installed any of them on the high voltage lines, their use being limited to the low voltage cable systems. Some transmission companies have installed them but from all of the data that is available they seem to be still in the experimental stage. My own personal experience with arresters is somewhat limited. In the central part of California the only type used is the horn type, their installation generally being limited to the generating important switching centers. Lightning itself strikes the lines occasionally but the result is seldom serious. It may strike the line between poles and burn one or more wires entirely off without effecting in any way the insulators, pins or poles adjacent to where it would strike. During the past winter we had two occurrences of this kind where it struck the line and burned off two wires in each instance. In neither case were the insulators damaged and we would probably not have known what caused the trouble had we not found where the lightning had gone to earth through several poles near where the trouble occurred. This would bear out the truth of the theory that disturbances of this kind were local in character and the high voltage would not extend any distance over the line. This being the case, there is a question in my mind as to whether or not any type of arresters unless located at a great many points along the line will entirely eliminate the troubles due to high voltage conditions of this kind which are known to come up occasionally.

I note that comparatively a few automatic switching devices are used but that fuses are substituted at the substations.

A fuse is all right in its proper place. It will work satisfactorily on small transformer installations but for the larger sizes you need something more substantial than a fuse. At one time it was common practice to use fuses on transformer installations up to 3000 kw. but these are being rapidly superseded by automatic oil switches.

There is one piece of apparatus which the manufacturers have not made as great progress in the development of as they have in other lines of apparatus. I refer to the reverse current relay. There are several types of apparatus of this kind on the market but in almost every instance they become inoperative when the voltage drops below a certain point. Where you have a network fed from a number of different points interconnected in a great many different ways you want something that will automatically cut out a line on which there is trouble before the entire network is effected. Having two long parallel lines tied together at both ends trouble might occur on either line which would make it desirable to cut out the defective line at the receiving end leaving load on the good line. If the lines are long and trouble serious the voltage at the receiving end will very often drop so low that the reverse current relays will not operate. The result of this failure to operate is too often a complete momentary shutdown until the switching is done by hand control.

The simplest and perhaps as reliable a reverse current indicator as can be had is the ordinary induction wattmeter. I have used these to fairly good advantage both to determine the location of trouble and also as reverse current relays for cutting out defective lines.

E. F. Scattergood: I agree with the writer of the paper in recommending that generating stations be tied solidly to the transmission lines and that there be no automatic devices employed. As Mr. Wood has suggested, I believe such is the general practice in this section of the country at least. The objection to the automatic devices, so far as they have been developed, except, I believe, in the cases of branch lines, which are in the nature of feeders and represent only a small load, making any reverse current impossible, are greater than the advantages, because when one of these automatic devices goes out it often happens that others follow, thereby causing a great deal more trouble than originally existed and a great deal more delay and lack of continuity of service.

By way of illustration we may form a mind picture of several 30,000 volt feeders with automatic devices leading from a substation containing a bank of transformers connected to a much higher voltage transmission line by means of another automatic breaker. It has happened even in such a case that the operation of a feeder breaker caused the higher voltage automatic to open also, thus throwing off considerable load and causing similar breakers to go out elsewhere. It would be much better to run some risk of the transformers than to run the risk of the system as a whole being disturbed in that manner unnecessarily.

Mr. Wood, in his paper, very aptly suggested that probably, as the networks become more complicated, it will be desirable to operate with divisions entirely separated but arranged for paralleling at any time.

G. H. Stockbridge: There are a few things that I would like to call attention to, one in particular being the subject of running the two lines parallel through automatic switches in substations. I would like to ask if any experiments have been made along the line of paralleling at the generating station, say a certain number of transformers on one side and a certain number on the other side, to be separated in case of interruption, thus confining the interruption to one-half the load. We have been considering trying this, but there were some complications raised. I would like to know if it has been tried in this case. I notice the statement, " the details of the system of upkeep employed in connection with the transmission system have been carefully worked out as a great many of the interruptions in service may be avoided by proper maintenance of the lines." This is a broad statement. What would apply in one district would be entirely insufficient in another. For example, we find occasional inspection of the insulators is necessary. Possibly it might require a complete inspection annually of our main transmission lines to insure us from interruption.

I also note that it is provided that when the patrolman working on the line makes his inspection that the lineman makes a solid connection to the ground with a cable. This belongs, of course, to the part of the system where the circuits are on separate lines. With the Edison Company in California, where the two lines are run on the same poles, we find it is essential for the man working on the poles to ground both ends of the circuit.

This table of service interruptions is, as I said before, particularly interesting to the operating engineer, showing as it does the causes of the various interruptions and I am surprised to find the causes are relatively few as compared to what they are in Southern California. In fact, I think in Southern California we have almost everything from balloons to birds on poles, including shepherds who leave their flocks long enough to climb a pole and try to magnetize their knives on a 60,000 volt wire.

The porcelain insulator shown in the paper is familiar to our Southern California engineers as being the old type of insulator used on the 30,000 volt line running from San Antonio Canyon into Los Angeles. When they were first installed we had very little trouble but when the load increased, when we had to use both circuits, there was considerable trouble from pole burning, similar to what Mr. Downing has experienced on his lines. This was eliminated to a large extent by taking a piece of galvanized iron and putting it on the top of the bottom crossarm to provide a conductor between the two arms for the leakage current. We found practically all the fires were caused by leaking across the gap between the top and bottom arm and by providing a channel for this we had but little trouble.

I am interested in the apparatus for taking care of lightning and so forth by air gaps. Our experience with air gaps in this country is not very satisfactory. We found the discharge point varied so much with the condition of the atmosphere. A gap which would be pressure-safe in dry weather would discharge more in foggy weather or a heavy mist. Perhaps there is some way of eliminating this besides installing electrolytic lightning arresters in series with them. If that is so, we would be interested in knowing what it is.

R. W. Van Noorden: Professor Cory gave us a little outline of what was called the psychological side of the telephone business. In other words, he wanted to show that the working of different systems was not altogether dependent upon the inventions and improvements that had been made. There is some question as to whether one system is an improvement over the other or not. In working our power plants, we have a psychological element, it is not like the one Professor Cory spoke about but is more material. I don't suppose there are any two power plants that are exactly alike. There are no two power plants that have exactly the same conditions under which they must operate, and yet there is a great similarity between all plants, let us say, of a certain size. In comparing the working of the Snoqualamie Company and those of California companies, there are many similar problems, but in order to understand these the engineer must understand a great many solutions which he does not learn when buying his machinery, or installing it, or of which the designing engineer may know nothing. I have seen in many cases, where a plant is started for instance and has been running for a year or two, there are changes made, and the engineer will say, " This has cost us more than if we had it in the first place," or " If this thing had been built in such and such a way it would have operated better." Now, the designing engineer did not know that. Possibly he could not have forseen it, but he should have, and as we go along in the science of this work we are learning these things and learning them from the operating end. The point I want to bring out is this, that this paper instead of being simply a description of what a plant has done day by day is really of the utmost importance in helping us to decide what we must provide for in our new developments, and it is just as Mr. Downing said, if the operating engineers would only have nerve enough or be permitted, to come out and give records of this sort, it would do more good to the engineering world than almost anything else that we could get. I am sure I have read this paper with the greatest of pleasure, and while there are many points that come up for discussion among engineers there are points that settle moot questions, questions of theory.

For instance, at one place the author states that if he did not have a Tirrill regulator which held up the voltage he would have had much less trouble in momentary interruptions with synchronous machines. That immediately brings up the subject of the old question between automatic and the non-automatic—I am not referring now to telephone operation, I am referring to power house work. Our experiences on the Pacific Coast have gone to show that the non-automatic workings have been successful where automatic apparatus might not have been, and that is where the question of personality and the psychological study that the engineer has to make comes in. I wish we would have a few more of these papers and that the engineers would consider them of more importance than they do for discussion.

C. O. Poole: There are several features in the system that have brought out points upon which I have debated in my own mind for some time past. One of them is the segregation of multiple circuits by automatic switches. Personally, I have been very much inclined to Mr. Scattergood's views that a good non-automatic was very much better than a poor automatic. Our practice I refer more particularly to southern Nevada—has been to install automatic oil circuit breakers on branch lines and also to protect substation devices. We have found in our experience that a well adjusted, well constructed automatic oil circuit breaker in protecting substations on the high-tension, lines is more reliable than on the low tension. We have found it to work very satisfactorily. I have hesitated however to install automatic switches on the main transmission lines. I can understand, of course, that it may work successfully under Mr. Crawford's conditions. As I remember it, his lines are exceedingly short, and consequently the charge and reaction effects are not so great as on the 200-mile lines. I would like to ask if Mr. Crawford knows of such experience with those lines and if the circuit breakers have dropped out by the line reactions or capacity reactions after the short circuit has occurred. I notice that they use a large rheostat in the tail race for throwing on the circuit before the machine has fallen out of step. I would like to ask if this is one rheostat that is on the bus or a separate rheostat for the separate generators. We had some experience in this line. We installed a new plant and our governors were not put in operation soon enough and we had to control 300,000-kw. by hand, and when a short circuit occurred on the system we had an arrangement made whereby we could throw it over on the rheostat simply to hold the speed of the generator down, and I might add perhaps down to a very low degree, and it worked satisfactorily as long as the wires did not burn out in the tail race.

I note also in Mr. Crawford's paper he states they test the line by, I presume throwing it onto the bus system at the voltage. I would like to ask if he tests it before he closes the line. Also what type of ammeters he uses on the high tension side to indicate the currents.

Ralph Bennett: It has been suggested that we ought to do all switching on the high-tension side. Our system is a 100,000-volt system, delta connected, and we stopped that. We found that every time we switched the load on the high-tension side we got surges that were too great to stand. The insulation breaks down. Some of our transformers are 10,000 kw. and it takes days to get them back into service.

We have installed at each end of our line electrolytic lightning arresters and our voltage rise on loss of load is sufficient to discharge the arresters. We have set the horn gaps back until they are practically non-operative.

We have had in over two years of about 100,000 volts operation so little line trouble that we can say we have had none due to the voltage. We have had a good many bushings broken down and things of that kind but the use of 100,000 volts does not seem so very difficult to us. There is no corona.

Our interruptions are so mixed up with the interruptions of different customers that we hardly know which are ours. Perhaps when we have been operating another year we will be able to say that this, that or the other interruption is due entirely to our own trouble and due to a preventable cause. We cannot say so today.

D. D. Morgan: The Pacific Light & Power Corporation has no circuit breakers at the generating stations; everything is tied in solid. We use some of them on the feeder lines and they work very well. They have worked very well in separating the railroad service from the commercial service.

Our experience with electrolytic lightning-arresters has not been very great. We do not believe that they have done much good in regard to lightning. We have had quite a bit of trouble with our insulators breaking down and shattering on our Kern River system. It seems to be very hard to explain why in a great many instances.

W. B. Gump: I will mention a few points relative to the figures previously quoted as to the limiting quantity of power to be feasibly carried over a single transmission line. Considering first the one extreme, a small amount of power, say, 1000 kw., to be delivered at a point 150 miles distant from the generating plant, we find at once that the capital outlay in transmission is almost certain to be prohibitive. In other words: it is evidently far cheaper to install a steam or gas power plant at the point of delivery.

Taking now the other extreme, a 20,000 or a 30,000-kw. load to be delivered the same distance (150 miles), we certainly have to consider continuity of service. Therefore, the dependence which would be placed on one three-phase line under these conditions necessarily involves a large degree of uncertainty.

Stating the proposition in another way: How much can we afford to pay to insure the transmission system against interruption? Or, putting it in still another way: What portion of the total power generated can we afford to have out of commission for a more or less uncertain period of time?

M. T. Crawford: I will endeavor to reply briefly to all the questions. It is true that with our present arrangement we drop half our load at the main substations if one line goes out, but only for a few seconds, as the switchboard operators first act is to switch this load to the live bus without delay. This we have found to be a more positive and reliable way than to employ reverse current relays. These operators display excellent judgment and while their action is deliberate, it is positive. I remember one case several years ago when power went entirely off of one line, and on the other line only one phase was alive. The voltage dip was not severe enough to stall the two 500-kw. rotary converters, and they were kept in running on one phase, by pulling off all the direct current load. By doing this the operator kept current on the polyphase low-tension lines and carried the more important polyphase feeders for about fifteen minutes, with only single phase high tension supply, as the converters were generating for the dead phases. By that time service was again resumed over another line. I don't know of any automatic equipment that can do work like that.

As to multiplying lines—we have tried multiple connections at both ends and at the middle, but experience has been in favor of connection at the ends only, as we have more reliable operators and equipment at these places.

In regard to testing out lines. It is rare that we have to do this directly. If normal service can be maintained with the good line, the chief operator proceeds with some care in locating the trouble. In many cases farmers or others telephone in and report the location of trouble, as the fireworks display is something to remember especially at night. The telephone system is in duplicate on line, on each pole line, and the telephone wires are almost invariably burned in two at the point of trouble. Hence the section showing telephone trouble is nearly always the one having high tension trouble. This section is left open and the rest of the line thrown in, section at a time, at the pole switch, the oil switch at the generating station being set for instantaneous overload release at a light current value. These switches are completely equipped as automatic circuit breakers for this purpose, and the automatic trip kept cut out during normal operation.

The water rheostat referred to is one large unit provided with an oil switch and panel the same as a feeder, and is thrown directly on the bus. Iron wire coils give good results, and I have also made excellent rheostats out of sheet iron. An iron ribbon 2 in. wide by 0.018 in. thick will carry 2000 amperes continuously if supplied with cooling water. It must be in one continuous strip (made by cutting a sheet zig zag) and well supported mechanically.

Our electrolytic lightning arresters have given us fair service on the whole, and we have two makes. They will take line surges from switching and other causes, although when the surge is repeated several times in succession we have had it burn a path right through the trays to ground.

We have only few expulsion type fuses at small stations, and prefer a series trip oil circuit breaker. Our switch experience has been that the additional cost of a more substantial mechanical construction is worth while. We are rebuilding all our pole switches, making them on the same general lines but of very much more substantial mechanical construction.

The failures of insulators were practically confined to the Everett line when it was equipped with 30,000-volt insulators which were not tested before acceptance, and then usually when a high voltage occurred from some other cause. The new insulators were individually tested by our representative at the factory before acceptance, testing each shell for its share and then the assembled insulator at a rain test of 120,000 volts for five minutes. They measure 14 in. in diameter at the large petticoat.

The patrolmen have each a separate section of line, the maximum single patrol being 20 miles. They are stationed at the middle of their territory, and in such a way that available linemen are only 10 miles apart.

A paper presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 27, 1911.

ELECTRICITY IN THE LUMBER INDUSTRY

BY EDWARD J. BARRY

The adoption of electricity for power in the lumber industry of the Northwest is of comparatively recent date although conditions are peculiarly favorable to its use. In the greater number of instances power can be generated locally at a very cheap rate by utilizing the waste products as fuel. These waste products have, so far, little commercial value and in the past any fuel in excess of the quantity required for the steam units and auxiliary machinery has been conveyed to a burner and destroyed. Saw mills, as a rule, are located in remote and sparsely settled districts where the problem of transportation to markets where the by-products of sawdust, shavings and inferior slab wood could be used, makes it scarcely worth while.

The generation of electricity for power offers a method of conserving this wasted energy by opening up a wide field for its application to the many demands for power outside of the sawmill itself. A brief record of the use of electricity in the mills of the Potlatch Lumber Company at Potlatch and Elk River, Idaho, illustrates these conditions. The Potlatch mill with a daily capacity of 750,000 feet, is one of the largest in the West and the power demand increased beyond the capacity of the steam units which consist of a 1500-h.p. corliss engine, belt-connected to line shafting, for the sawmill, and one 1100-h.p. corliss engine for the planing mill.

A year ago one 800-kw. low-pressure, 2200-volt, three-phase, 60-cycle turbine generator was added to operate on the exhaust of the 1500 h.p. engine and has increased the available horsepower output by 60 per cent.

The turbine can also be operated on live steam if necessary in the event of a shut-down of the corliss engine.

The output of this 800-kw. set is used to drive the machinery in the box factory, a 300-h.p. motor driving the blower on the shavings conveyor; it supplies power for the machine shop, car shop and pump house; lights the mills and town at night, and during the summer months supplies 200 h.p. to a local brick-making plant. No increase in boiler capacity has been required and operating conditions are such as to occasion very little extra expense in the way of attention. Storage battery locomotives are employed to handle the lumber from saw-mill to dry-kiln and from dry-kiln to planing mill. These locomotives are seven tons in weight, including battery, and have a start-draw-bar pull of 3,600 lb. (1632 kg.) and a running draw-bar pull of 1500 lb. (680 kg.) at four miles (6.4 km.) per hour. Two 40-kw. belt-driven units are installed for charging the six locomotives employed. Four spare batteries are kept in reserve and can be placed in position on the locomotives in a few minutes in the event of a battery failing.

Snow has given considerable trouble in former years throug blocking the tracks and this winter there was designed and p into service an electrically-driven snow brush which has prov eminently successful. The brush consists of a wooden cylind with rattan canes projecting 16 in. (40.6 cm.) from its surfac This cylinder is driven by a chain geared to a 15-h.p. compoun wound motor mounted on the forward part of a lumber car, t battery for driving it being in the rear. After a heavy fall snow this rotary plow is sent over the tracks clearing them co pletely and allowing work to proceed without interruption. Le batteries are at present in use on the locomotives but nick iron batteries have been ordered and it is intended to change o to this type as circumstances permit.

When it was decided to adopt electric drive for the Elk Ri mill, at present under construction, a complete test was m to determine the horse power required to drive the differen machines in the mills.

The machines under test were disconnected from the line-shafting and belt-connected to a motor of the estimated horse power. Wattmeter readings were taken over a period of ten hours on normal load and from this data the necessary information was obtained.

The band mills were found to take from 30 h.p. at no load to as high as 275 h.p. on full load, and it was decided to install 200-h.p. wound-secondary motors for use at Elk River. There are three motors of this type.

The edgers have 75- and 50-h.p. squirrel cage motors, respectively.

The planers in the planing mill are driven by 75-h.p. motors. In cases where it was considered desirable, liberal use has been made of wound-secondary motors.

The power equipment at Elk River consists of one 800-kw., 600-volt, three-phase, 60-cycle turbo-generator and one 500-kw., turbo-generator. A switchboard of eleven panels installed in the turbine room, controls power and lighting feeders to the different departments.' For lighting the town and outlying districts the voltage is stepped up to 2,200 volts, with 2200–220–100–volt step-down transformers at centers of distribution.

A 50-kw., 600-220-100-volt transformer is used for sawmill lighting, and in the event of a burn-out provision has been made at the switchboard for connection to the steam exciter set, which can be switched over for this work alone. The 25-kw. motor-generator exciter set can then be used for both generators.

A 50-lamp regulating transformer is used for the series arc system on the log pond and for street lighting in town. The sawmill is intended to run nightly thus making the question of lighting one of importance. This is especially so in lumber grading which calls for powerful, evenly distributed light, with an absence of shadows. Experiments made at Potlatch have convinced us that tungsten clusters and single drop lights give the best effects and in the end cost least for maintenance. Arc lamps inside the mill have been discarded entirely. In the filing room, the saw sharpeners and stretchers are driven by individual motors of two and three h.p. and the small forge has a motor-driven blower. The entire system, both power and lighting, is installed in conduit, reducing the fire risk to a minimum.

Electricity will be used on the log pond for dredging, as the pond bed has a tendency to slit up and impede the passage of logs to the conveyor.

It is intended to use a rotary cutter directly in front of the intake of a powerful pump and convey refuse to the shore over pontoons supporting the pipe line. The pump and cutter will operate from a barge to which the supply wires to the transformer will be attached. The voltage will be stepped down from 2200 to 440 volts at the motors, and three cable drums will pay out or haul in the wire according to the location of the dredge. It has been decided that a 35-h.p. motor will be required for the pump and a 25-h.p. motor for the cutter. If necessary a small motor may be installed for raising or lowering the arm supporting the intake pipe and cutter.

As soon as weather conditions permit the Potlatch Lumber Company intends to experiment with electric drive on the logging machines in the woods, with the view of superseding the steam donkey engines at present in use. There are many drawbacks to the use of steam engines, not the least of these being the ever present risk of fire from cinders and sparks. Every care is taken to minimize this risk but the wholesale devastation in the forests of Idaho, Washington and Oregon last summer has naturally turned the attention of lumber companies operating in the fire areas, towards any method which offers even a partial solution of this difficulty. Water for the boilers must be hauled wherever the donkey engines are located as it is useless to depend on getting it locally except in the rare instances where a stream is within reach. Fuel has to be cut down and sawn into the proper lengths, creating a considerable labor item. A watchman has to be on duty every night during the winter to keep the water from freezing, an occurrence more frequent than desirable, when it comes to starting up in the morning.

Electric logging presents one or two new features in transmission work, the chief difficulty being that the location of the consuming end of the line must, of necessity, change constantly. The transmission line must be guarded against the danger of falling trees, but as it will be always in the rear of logging operations it will be possible to follow the track over logged off land, reducing the risk to a possible interruption, in hilly country, through a tree rolling down from higher ground. When a section has been logged over and a permanent change has to be made in the direction of the transmission line it would appear that a saving could be effected by installing light lattice work steel towers in the first instance. The towers could be set down and guyed to convenient stumps. The line would parallel the logging railroad practically throughout its entire length and when it was necessary to change the location these towers could be taken down and loaded on the cars. The wires and insulators would have to be removed in any case and, as the construction crew will be on the spot, it would take very little extra labor to remove the towers also. The length of span will be from

350 to 400 ft. (106.6 to 121.9 m.) and the height of tower from ground 30 ft. (9.14 m.). The size or character of the wire will not be settled definitely until the nature of our requirements is known. The current will be 22,000-volt three-phase, 60-cycle. At each logging engine there will be a portable sub-station containing one 150-kw., three-phase, 22,000-550-volt, step-down transformer. From the secondary of the transformer a three-core steel-armored flexible cable will be led to the motor. This cable will be built up in sections with suitable connectors until a limit of 1,800 ft. (548.6 m.) is reached, when it will be necessary to extend the line. This distance will permit of clearing a large area, as the steel logging cable has an effective reach of 3,000 ft. (914.4 m.). The motor will be of 150 h.p. capacity, and of the phase-wound type driving by means of friction pulleys.

A controlling panel with current-limiting relay to automatically introduce resistance into the rotor circuit in the event of the log striking an obstruction, will be installed on the platform beside the motor. This principle has been applied with success on electric shovel work and prevents the annoyance of a constantly tripping circuit breaker. A circuit breaker will be used to prevent damage to the motor should the power demand rise to an excessive value in the event of the obstruction proving beyond the capacity of the machine.

If successful there is scarcely a limit to the uses of a power supply carried into the forests and the natural outcome would seem to point to an extension embracing a complete electrification of logging railroads. Within four miles of Elk River there are two waterfalls of 85 and 102 ft. (25.9 and 31 m.) respectively which could supply upwards of 5,000 h.p. There are numerous little settlements at present remote from any center of power supply, which doubtless would welcome the opportunity to secure energy to assist in development.

In submitting this paper to the A.I.E.E. the writer would appreciate any record of experiences of members in similar circumstances and would be glad to furnish any further particulars in his power on matters relating to the electrical side of the lumber industry.

DISCUSSION ON "ELECTRICITY IN THE LUMBER INDUSTRY." LOS ANGELES, CAL., APRIL 27, 1911.

R. L. Noggle: I might say just one word in favor of electrically operated sawmills, and that is this: You will find that in using electricity, in place of steam you will save on your insurance. Where I am in the northern part of Idaho, we have started to furnish power to two different mills which consume some 750 h.p. The only talking point we could impress them with at all was that of insurance. We are running our plant entirely on refuse and shavings from the saw mills and in turn sell those people 600 h.p.

J. A. Lighthipe: I think the advantage in the lumber industry, if electrically operated, is not so much in operating the sawmill as it is in supplying power to the logging camp. For years they have been trying to get hold of a large portable saw that would take care of the logs. I would like to ask how they have succeeded. They saw up a tree seven or eight or nine feet in diameter, and the question of operating those saws is quite a question. We made a failure at Folsom, not so much in operating the mill as in the lack of logs to saw. At that place we had a great dispute over the amount of power necessary to saw. The boss sawyer used to take a log and jam it through as fast as he could. He would crowd the mill to the utmost. That is about the last experience I have had with any large logging concern. Inquiries have come from the neighborhood of Seattle to know if anything had been developed for an electric saw out in the lumber camps, away out where they drop the logs and section them up. That is where it is needed more than anywhere else.

C. Pemschel: In the first part of this paper in which the author describes the installation at the Elk River & Potlatch Lumber Company, he informs us the hand mills vary in horsepower from 30 to 275 h.p.

I think it would be very interesting for us to know the horse power under the different conditions that the mill is operated. The size of the cut and feed. This same thing also applies to the edges. I also notice that he says that the planers in the planing mills are driven by 75-h.p. motors. Seventy-five horsepower is rather large for the largest size planers and I surmise that one 75-h.p. motor drives a group of planers. Any information that he has, that is, the horse power, that these planers take under actual operating conditions I am sure would be very interesting to the readers of this paper.

The second part of this paper in which electric logging is taken up is interesting to me as I have given this matter considerable consideration and thought and have worked out the scheme of operating these donkeys by means of compressed air and last July read a paper before the Logging Congress in Portland on this subject. A copy of this paper can be seen in the August issue of *The Timberman*.

J. A. Lighthipe: Seventy-five horse power is nearer right than twenty-five.

The tendency in all of the mills is to force the machines. Power is very cheap and time is very costly and they are apt to overcrowd everything. I found that particularly in the great big band saws where the boss sawyer was trying to drive the logs through as fast as he could. The planers did the same way. They fed those machines up to the limit. The work in these camps is not to be compared with any railroad shops you ever saw. The lumber is cheap, power is cheap, and labor is high.

Ralph Bennett: It appears to me that you were using your planer for resizing. Taking off some very heavy cuts to get a different sized material. That need not occur in a lumber yard or at the mill.

I installed about two years ago a rather large planing mill for this district in which we used electric drive throughout, and turbines for generating. That mill has 40 h.p. on each planer, and they handle the material very nicely.

In this same connection I investigated the possibility of using electric power in their saw mills, and installed a 300-kw. turbine in what they speak of as Mill B. They propose to rebuild Mill A, or build a new mill electrically driven. We found that the 250,000 B. M. mill took about 900 h-p. running idle, 1100 on normal load, and possibly 200 more when all three bands happen to catch at once. The amount of power given in this paper for the bands would not be at all applicable to Pacific redwood mills.

The Potlatch method of logging must also differ somewhat from that used in the redwoods, because it is necessary there to handle not only a logging engine but a yarding engine. The logging engine could be reached by a wooden pole line along the railroad. The yarding engine is, however, three thousand to five thousand feet beyond the road engine on a steep hillside, without any permanent surroundings whatever, and it would be necessary to reach it with a cable. These logs are at present sawed by hand where they are felled. Indeed an enormous possibility in labor saving in the woods exists here. Fuel for the road engines represents less investment than fuel to the yard engines. The road engine is reached by an oil tank car, but oil has to be packed to the yard engine. This oil is brought from Southern California, and taken into woods where they are burning their waste to get rid of it.

At the mill it is true that fuel is valueless. It is also true that the cost of preparing and firing wet sawdust is high. There are times when steam cannot be kept up. By feeding more of this material to refuse burners, and less to the boilers, it can be disposed of at much less cost. The economy of high grade turbines is therefore an advantage after all.

Most modern engine-driven mills have two engines, one for the front and one for the back of the mill. A breakdown in either engine shuts the mill down. Two turbines of the same capacity, both running, would be but part loaded. A breakdown on either turbine would permit the running of the remaining installation with the uninjured turbine.

The author of the paper speaks of the use of storage battery locomotives in the yard. There are now in operation in California and in the southern states, a great many monorail systems, in which the car travels on an I beam rail elevated 25 or 30 ft. above the yard. When properly installed, this will cover the entire storage area, permitting it all to be used for lumber storage purposes. If lumber is piled in stacks in proper shape and tied together, it can be handled into the pile and stored without any hand shoving whatever, and still in the package taken aboard the vessel or car and so transported as a unit from the sorting table to the wholesale lumber yard, thus reducing the cost of handling and storage to a minimum, at the same time producing under proper conditions a much better grade of lumber with quicker handling.

A paper presented at the Pacific Coast meeting of the American Institute of Electrical Engineers, Los Angeles, April 27, 1911.

A POWER DIAGRAM INDICATOR FOR HIGH-TENSION CIRCUITS

BY HARRIS J. RYAN

INTRODUCTION AND SUMMARY

The power diagram indicator was produced as a feasible, inexpensive instrument to observe dielectric or similar stray power losses that occur in high-tension circuits.[1] A cathode ray-pointer is used to trace the power diagram. It is actuated electrostatically. The pressure of the high-tension circuit applied to " quadrants " causes a proportional displacement of the ray-pointer in one axis; the pressure drop between the terminals of a condenser in series with the high-tension circuit is applied to the other pair of quadrants and gives the ray-pointer a quadrature velocity proportional to the current. The ray-pointer is thus made to trace a diagram that encloses an area proportional to the e.m.f.-current-time product.[2] Alternating current will produce a closed diagram or " card " having an area which is proportional to the energy of the circuit delivered per cycle. At constant frequency, therefore, the card-area measures the power applied in the circuit. The form of the card tells of many things besides the amount of power just as the steam engine indicator card does in steam engineering.

The pressure and current ranges of the instrument are controlled by values of the capacities of the condensers employed. The capacities of the operating condensers may be varied indefinitely so that the working range of the instrument may be

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[1] The instrument may also be employed as a dielectric hysteresis diagram indicator as discussed under *Theory.*

[2] For those who prefer it a mathematical demonstration of this relation has been given under *Theory.*

varied also indefinitely. The instrument was used to measure the dielectric loss that occurred in a one-quart (0.946-liter) sample of insulating oil, caused by moisture or other impurities. The values encountered were 0.03 watt at 9,000 volts. See Fig. 9. This is the smallest high-tension power measured in the trying out tests. The highest power measured was a corona loss of 750 watts that occurred at 130,000 *root-mean-square approximate sine-wave volts* on a high-tension laboratory line. See Fig. 7.

The *integrity* of the instrument depends upon the quality of the condensers employed. If the condensers are good the indications of the instrument may be relied upon fully. The *accuracy* of the instrument depends upon two things:

1. The uniformity of the electrostatic fields set up by the deflecting quadrants.

2. The variation in the potential delivered by the electrostatic machine that is used to produce the ray-pointer. This causes a slight corresponding variation in the deflection of the ray-pointer.

In regard to both these causes of error it may be said that where but little care has been used in mounting and adjusting the quadrants and in operating the electrostatic machine the errors remain *within* 5 *per cent.* An accuracy that is sufficient for this class of work is, therefore, easily attained.

The indicator is conveniently calibrated by loading the test circuit for a known amount of power or by computing its scalar constant from its inherent constant obtained at low pressure and the capacities of the condensers employed.

The instrument has been found satisfactory for the study of high-tension insulation and insulators, dielectric losses in high-tension transformers, insulating qualities of transformer oils as affected by moisture, suspended impurities, etc., losses into the atmosphere from high tension lines, etc.

The principles of construction and operation, source and cost of this instrument are given under *Structural Details.* It is comparatively inexpensive, and an ordinarily capable person should have no difficulty in operating it to his entire satisfaction.

In closing, mention is made of the corresponding type of power diagram indicator operated magnetically using inductance in lieu of capacity control. Such an instrument is satisfactory only when operated on low-tension circuits. Because there are abundant facilities for work of all sorts on low-tension circuits, the magnetic form of this instrument is, at present, of comparatively little importance. The ray-pointer may also be operated by a combination of static and magnetic action from which additional forms of power indicator are made possible.

THEORY

In Fig. 1, u is a pointer that traces the diagram $x\,y\,x\,y\,x$. In so doing its motion is made up of two rectangular components determined by the following relation referred to o, the pointer's normal zero position:

The vertical displacement of the pointer, y, is proportional to the instantaneous value or the e.m.f., e, in a given alternating current circuit. By calibration these become equal.

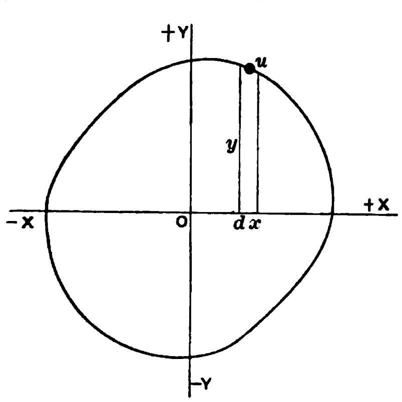


FIG. 1

The horizontal velocity of the pointer dx/dt is proportional to the corresponding instantaneous current, i. By calibration these also become equal. Thus

$$e = y$$

$$i = \frac{dx}{dt};\; dx = i\,dt$$

And $\quad e\,i\,dt = dw =$ *energy increment*

Substituting $\quad y\,dx = dA =$ *area increment*

Therefore $\quad dA = dw$

Integrating $\quad \int dA = \int dw$

Wherefore $\quad A = W$, *i.e. area = energy.*

It follows that at constant frequency the areas in these cards by calibration equal the electric powers that produced them.

Cathode rays actuated electrostatically by means of four quadrants are employed for the ray-pointer. See Figs. 2 and 18. Between two opposing quadrants an electric field is established by the application of the e.m.f. impressed upon the testing circuit. Thus a displacement of the ray-pointer is produced, proportional to the applied e.m.f. The remaining quadrants are connected to the terminals of a condenser in series with the testing circuit. By this means the ray-pointer is placed in the presence of a quadrature electric field that is due to the pressure drop produced in the condenser by the testing circuit current. The rate of change of such pressure drop, and therefore of the electric field, is proportional to the current and the ray-pointer is thereby given a quadrature velocity that is proportional to the current. An instrument thus arranged and operated behaves in accordance with the above theory.

Theory for the Dielectric Hysteresis Diagram Indicator. When the specimen is a dielectric through which the test pressure sets up current only by condensance, the electric field established between the velocity quadrants is a true replica of the field in the dielectric. It is then that the ray-pointer is displaced proportionally in one direction by the *impressed e.m.f.* and in the quadrature direction by the *electric field of the test specimen.* The resulting diagram when produced with alternating e.m.f. gives *the relation throughout the cycle between electric force and electric field.* If the field lags behind the force, dielectric hysteresis is present. The diagram will develop this relation at every phase of the cycle. It will enclose an area that is a measure of the hysteresis. The above theory continues to apply because no change in the operation of the instrument has been made. The area of the card, is therefore, proportional to the energy lost through dielectric hysteresis per cycle and to the corresponding power lost at constant frequency. The application specified under *Methods*, Fig. 8, is an example of the way in which the instrument may be used to secure dielectric hysteresis cards. Manifestly if conductance is present the card will include the form and area due to a combination of both losses. A corresponding difficulty arises in the use of a magnetic hysteresis diagram tracer.

METHODS

The cathode ray-pointer is made up of electrons discharged from the cathode at a negative potential around 10,000 volts. The potential, however, of the speeding electrons is zero having been lost by acquiring a " velocity due to (electric) head " just as is the case with a water jet in hydraulics. It follows that for best results the middle values of the displacement and velocity pressures applied to the instrument quadrants and the cathode ray-pointer should all have a common " zero potential ".

It is best, therefore, to cover the electrostatic machine, used to produce the cathode ray-pointer, with a wire net and to ground such net and the positive terminal of the machine; and to divide the velocity condenser into two parts, connected in series at the center of the source or at the center of the test circuit, with the connection between the condenser parts also grounded. This will balance the behavior of the ray-pointer in the presence of the four quadrants. Obviously a source which through accidental grounding, faulty insulation, etc., presents an e.m.f. that is unbalanced with respect to earth potential and is not so convenient. In such case it is necessary that the mid-potentials of the displacement and velocity pressures and the potential of the ray-pointer have a common value. The exact details to accomplish this depend upon the particular circumstances and must be left to the intelligence of the experimenter. Fig. 2 gives the connections when the velocity condensers are connected at the middle of the source and Fig. 3, when connected at the middle of the testing circuit.

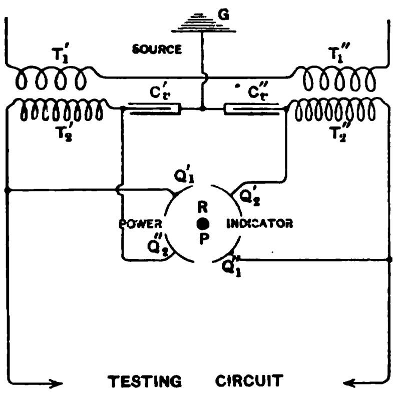


FIG. 2

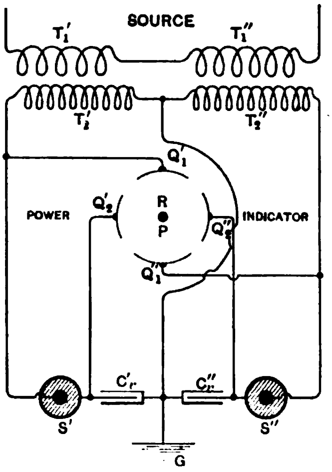


FIG. 3

The e.m.f. that will deflect the ray-pointer over the maximum range depends upon the dimensions adopted and the manner of mounting the quadrants. It can be made as low as 200 volts, maximum. It is 900 volts, maximum, in the instrument that was used for the trying-out work referred to herein. See Fig. 18. As the instrument is suited primarily for high-tension work it follows that a pressure range multiplier must generally be used. Some form of condenser-type multiplier is best for this purpose.

Fig. 2 is repeated in Fig. 4 and the pressure multiplying condenser, C_d^{I} C_d^{II} C_d^{III} C_d^{IV}, has been added. This is called the displacement condenser as used in the trying-out experiments. A photograph of this condenser is reproduced in Fig. 5. It is an air-dielectric condenser. The electrodes, C_d^{I} and C_d^{IV}, were made, each of four 7-ft. by 5-in. (2.133-m. by 12.7-cm.) cylinders of galvanized sheet iron, electrically connected. To form the spherical ends of the cylinders, float balls were used, such as are employed in household plumbing. Between these electrodes the source-pressure establishes an electric field. Midway between them is mounted a ground plate *o o*, and on either side two field tapping plates, C_d^{II} C_d^{III}, which are connected to the displacement quadrants, Q_2^{I} Q_2^{II}. In this way an exact replica miniature of the large electric field is produced between the quadrants, Q_2^{I} Q_2^{II}, that will displace the ray-pointer in accurate proportion to the total source of pressure. The cylinder-electrodes are swung from a frame by insulating cords and by means of pulley tackle one may conveniently adjust the positions of the cylinders from the floor so that they will be near to or far from the tapping plates, C_d^{II} C_d^{III}. Insulating cords suspend the tapping plates on either side of the ground plate, *o o*, in such a manner as to draw them together. Hard rubber set screws are used to determine their separation from the ground plate as shown in the photograph. In this way the maximum pressure range of the instrument is quickly adjusted from 900 to 250,000 volts.

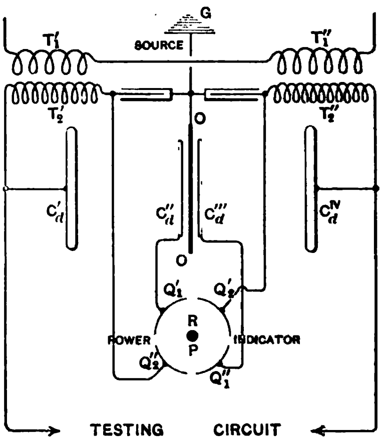


FIG. 4

When the velocity condensers are connected at the center of the source, see Fig. 4, and the testing circuit is open, the instrument will indicate *no power*, provided there is no dielectric loss in the transformer, displacement condenser and their connections. It will indicate the vector-sum of the combined charging current of the high-tension circuit of the transformer and the displacement condenser at the delivered e.m.f. It will indicate each of these, *i.e.*, by the velocity or displacement of the ray-pointer, according as one or the other is short-circuited out. The air-dielectric pressure condenser is easily insulated so that it will display no dielectric loss. Good transformer oil, free of water, which will break down at 50,000 volts between half-inch (12.7-mm.) spheres separated one-tenth inch (2.54 mm.) caused the 120,000-volt transformer outfit employed in this work to operate at full pressure without appreciable dielectric loss. When, however, there is present a dielectric loss in the source transformer it must be observed when the testing circuit is cut out at each particular voltage and a corresponding correction must be made.

FIG. 5

The method wherein the velocity condensers are connected to the center of the source is preferred, especially where it is not practicable to make the corresponding connection at the middle of the testing circuit. The measurement of the power lost in corona about a high-tension transmission line is an example of this sort. The nest of power cards given in Fig. 6 was obtained through an early trial of this method. The test specimen was the atmosphere surrounding a laboratory line with the following specifications: diameter of conductor 0.085 in. (2.159 mm.), interaxial distance 12.5 in. (31.75 cm.) length 130 ft. (39.624 m.). Card *I* has no area; it was taken at 44,000 root-mean-square approximate sine-wave volts, just before the atmosphere about the line broke and just below the pressure at which the card began to open out with an area. Card *II* was formed at 53,400 volts and card *III* at 64,000 volts. The cards in Fig. 7 were also obtained by this method. In this case card *III* was made at 128,000 root-mean-square approximate sine-wave volts, by the atmosphere loss about a laboratory line having the following specifications: conductor 5/16 in. (7.938 mm.) diameter, seven-strand, tinned, steel guy cable; interaxial distance 36 in. (91.44 cm.), length 128 ft. (39.014 m.). Cards *I* and *II* were formed by known loads applied in the testing circuit for calibrating purposes. Card *I* was made by the core loss of a 60,000-volt transformer applied on the high-tension side; Card *II*, the same plus load of seven 16-c.p., carbon filament " calibrated " incandescent lamps connected to the low-pressure secondary of the loading transformer and arranged so as to operate at about normal candlepower. The results herein obtained are given in the following table:

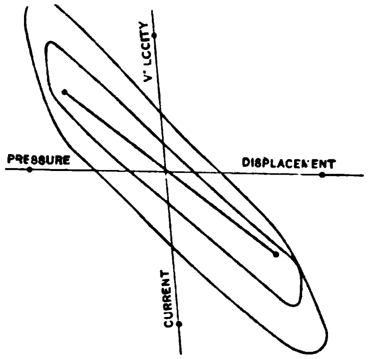
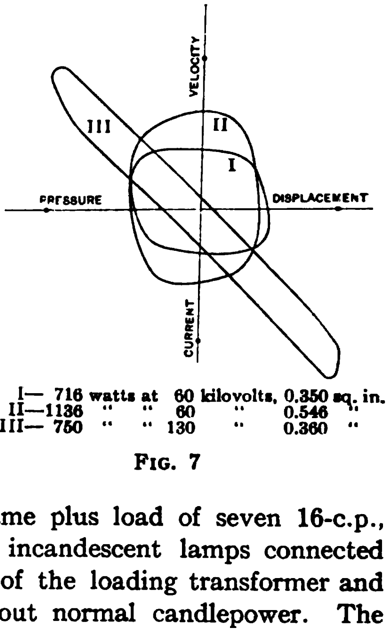


FIG. 6



I— 716 watts at 60 kilovolts, 0.350 sq. in.
II—1136 " " 60 " 0.546 "
III— 750 " " 130 " 0.360 "

FIG. 7

	Areas of original cards in sq. in.	In sq. cm.	Calibrating loads in watts	Watts per sq. in. by calibration	Watts per sq. cm. by calibration	Observed corona loss in watts
I	0.35	2.26	716	2050	317.88	——
II	0.546	3.52	1136	2080	322.22	——
III	0.36	2.32	——	——	——	750

The formation of an area in the power diagram began at 112,000 volts corresponding with the start of the "*noise*" and a few per cent under the pressure that started the visible corona.

Where the specimens under test take a small charging current and the dielectric losses are comparatively small it is best to arrange them in a testing circuit so that the velocity condensers can be used at the potential middle of such circuit rather than at the middle of the source-transformer. In this way the presence in the velocity condensers of the transformer and displacement condenser charging currents is avoided, making the indicator solely responsive to the dielectric properties of the specimens. The application of this method is perhaps best illustrated in the arrangement adopted for testing transformer insulating oils, shown diagramatically in Fig. 8. The specimen of oil is divided and placed in a duplicate pair of tinned pans. The pans are mounted over a metal ground plate, $O' \, O'$, and separated therefrom by an air-dielectric space sufficient to form the velocity condensers as shown in the illustration. Bits of new empire cloth, thin sheets of hard rubber, etc., do very well to support the oil pans and to form the condenser gap. The radius of curvature of the edges of all metal parts must be large enough so as to be far within the corona formation limit in either the air or the oil. To try out this method a

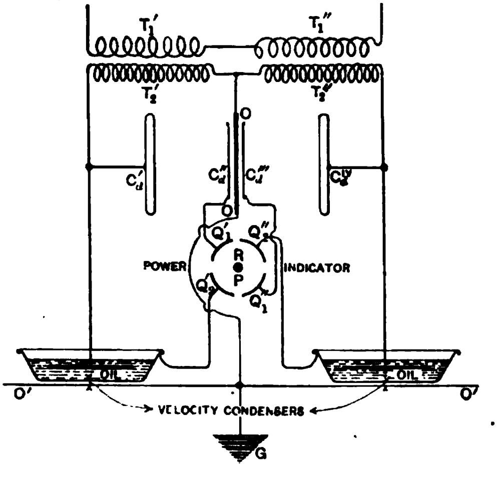


FIG. 8

specimen was selected from a supply of oil that had been exposed to the atmosphere in the laboratory and which had plenty of opportunity, therefore, to absorb moisture. On test at 9000 root-mean-square approximately sine-wave volts, by this method, card *I*, in Fig. 9, was obtained. The area of the card corresponds to about .03 watts. The oil was then taken from the pans, tested with lime to remove the water and after filtering was replaced in the pans and the test repeated. At 9000 volts the pressure that gave card *I* in the first test now gave the right line, *II*, showing no area and, therefore, no loss in the oil. The pressure was raised to 13,000 volts and the right line, no-area card increased from the limits, *II II*, to *III III*, showing that the dehydrating and filtering had made a vast improvement in the dielectric quality of the oil. The shape of card *I* tells an interesting story regarding the characteristic conductivity of the oil introduced by the impurities present, mainly water.

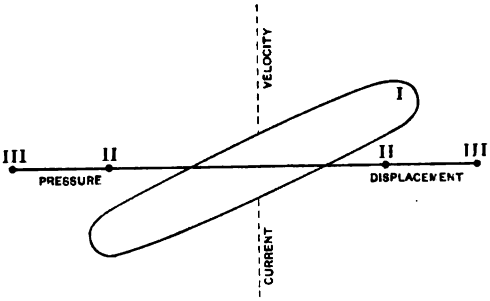


FIG. 9.—*I*—Area, measures 0.03 watt at 9000 volts

Those who are particularly interested in these matters will be amply paid for their time and effort spent in making their own comparative studies of the cards in this and the two preceding illustrations.

One other experiment was made to try out this method wherein the velocity condensers are connected at the middle of the testing circuit. The purpose of the experiment, in addition to trying out the method, was to determine whether soot on a wire would constitute the " dirt " and that is said to lower the e.m.f. at which corona loss begins.

Two steel wires, *W' W''*, Fig. 10, were mounted each at the axis of a 10-ft. (3.048 m.) length of ordinary 6-in. (15-24-cm.) stove pipe placed over a common ground plate. The relative positions of the pipe and ground plate were quickly adjusted so that the velocity condensers thus formed had the requisite capacities to produce a desirable current-velocity ray-pointer deflecting range. The source pressure was put up until the double line on the indicator screen parted to form an area thus indicating the fact that a zone of atmosphere about the piano wires had broken down causing a loss in power. After noting the source pressure that did this to be 22,000 root-mean-square, approximate sine-wave volts, it was turned off. A lighted candle was then attached to a suitable carrier made of soft copper wire, hooked to the piano wire and adjusted so that the flame would smoke it. By means of a string attached to the carrier the candle was made to pass under and smoke the whole length of each wire. Pressure was again applied to the wires and increased to the point where the indicator showed the start of a loss card,—this pressure was observed to be 24,000 volts. The increase was evidently due to the appreciable increase in the diameter of the conductor produced by the covering of finely divided conducting carbon. It was the first experiment in which this method was tried out and determined that soot is not the kind of " dirt " on a conductor that will lower the value of the e.m.f. at which corona is first formed.

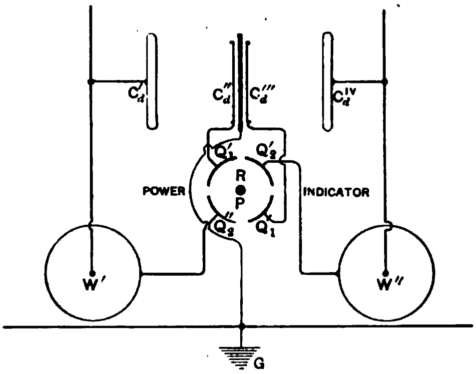


FIG. 10

At times it may be necessary in order to use the indicator to connect it on one side of the circuit in the same corresponding manner that a wattmeter is ordinarily connected. This can be done provided:

1. The indicator will produce true cards when the displacement and velocity quadrant potentials are entirely above or below the zero potential of the ray-pointer.

2. The conditions are so adjusted that the "ground" of the indicator with its electrostatic machine and the connections of the displacement and velocity condensers on the low-potential side of the line are at the same potential.

The first proviso was tried out at low pressure with the connections shown in Fig. 11. The source pressure, e, was applied to the quadrants, Q' Q''; the terminals of the velocity condenser C_v were connected to the remaining quadrants, Q_2' Q_2''; R was the loading resistance and I the instrument for reading the current. The power applied in this testing circuit was, therefore, I^2R.

Two cards were obtained, one at a given value of current I, and another at double that value or four times the power, *i.e.* $4I^2R$. These cards are reproduced in Fig. 12. The areas of the originals measured 0.067 sq. in. (43.21 sq. mm.) and 0.282 sq. in. (181.93 sq. mm.), respectively. The ratios of these areas is 4.21 to check with 4 which is a better behavior than was anticipated, especially because one of the areas traced was so small. There has been no opportunity as yet to try out the second proviso; however, with that no particular difficulty is anticipated. At all events in this repect the method will easily be applicable for detecting dielectric losses in all cases where one side of the source can be grounded.

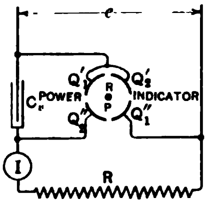


FIG. 11

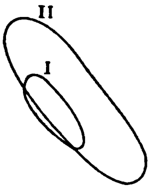


FIG. 12

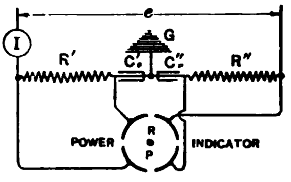


FIG. 13

The cards in Fig. 12 were obtained with neighbor-mounted quadrants; the ray-pointer that traced them was actuated by a composite field. For this unbalanced or onesided method of using the power indicator it is expected that better results will be obtained by tandem-mounted quadrants. With these the ray-pointer will be acted on first by one field and then by the other. Thus and by screening out the stray field set up by the high tension line, one should secure excellent results.

Originally it was not thought that the one-sided method would work. For this reason it was tried out only at the close of the series of trials merely for the purpose of working to the limits of the investigation assigned at the outset. When it was found to be quite feasible time did not permit to try out the method on high-tension circuits. A good testing load for such a trial would be a single high-tension line insulator. With the neighbor-mounted quadrants the cards must occupy one corner of the indicator screen; at all ranges they are, therefore, rather too small for comfort. The use of tandem-mounted quadrants should restore the use of the whole screen and the method should then approach the satisfactory character of the central connection method.

ACCURACY AND INTEGRITY TRIALS

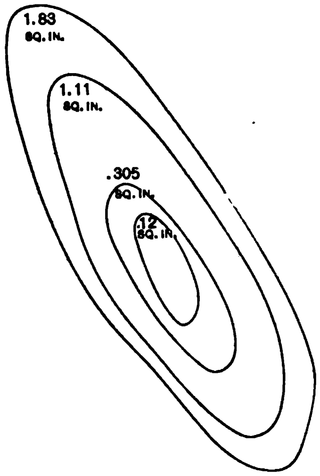
1. The character of the electric field as to uniformity, set up between a plain pair of quadrants, quickly made and easily mounted, was tested by applying alternating e.m.f. between one pair of quadrants and short-circuiting the neighboring pair. The quadrants were made and mounted as specified under *structural details*. The e.m.f's applied to the quadrants and the corresponding deflections of the ray-pointer produced were read and scaled and tabulated so as to permit of ready comparison. See table *I*:

Volts	Indicator deflections
140	150
280	271
420	413
560	555
676	688

This was not a complete accuracy trial. Composite fields deflecting the ray-pointer by the combined action of all four quadrants should also have been used. This test, however demonstrated that the accuracy required in the instrument is comparatively easy to obtain by a proper mounting of the quadrants. There is almost no end to the variation of the actual forms that may be given the deflecting quadrants. It is merely a question of putting enough time into the undertaking to produce quadrants so formed and mounted that the ray-pointer will be deflected with any reasonable degree of accuracy that may be desired.

2. The relation between areas and loading watts was tried

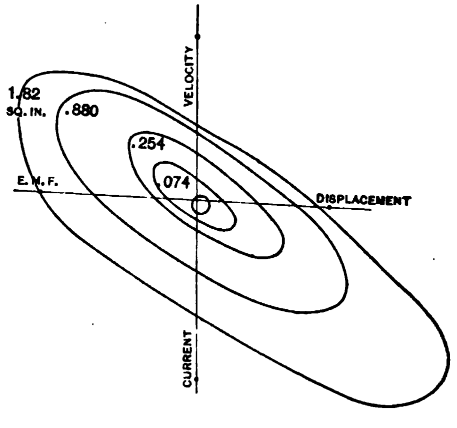
out with low pressures. The connections used are shown diagramatically in Fig. 13. The loading resistances R_1 R_2 were the ordinary "multipliers" used with alternating current instruments of the dynamometer type. The current through the loading resistances was read by means of the instrument, *I*, for which an ordinary alternating-current voltmeter was employed. In this way the nest of cards in Fig. 14 was obtained by making the proper changes in the loading current as indicated at *I*. The area of the original is given for each card. Fig. 14 also includes an "Integrity Table", *i.e.* a table of the card areas and the squares of their corresponding currents which are proportional to the power present and scaled so as to facilitate comparison. No attempt was made to secure higher proportional conformity of areas and the powers that produce them. The sort of work for which the instrument was developed does not require it. However, should it be so desired greater accuracy can be obtained by refining the method of making and mounting the quadrants and by screening the ray-pointer from the action of all stray electric fields.



Integrity table

	Powers.	Areas.
$38^2 + 11{,}500$ =	0.125	0.120
$60^2 + 11{,}500$ =	0.315	0.305
$110^2 + 11{,}500$ =	1.070	1,110
$145^2 + 11{,}500$ =	1.830	1.830

Fig. 14



Integrity table

	Powers.	Areas.
$31.5^2 \div 11{,}500$ =	0.086	0.074
$59^2 \div 11{,}500$ =	0.302	0.254
$100^2 \div 11{,}500$ =	0.870	0.880
$147^2 \div 11{,}500$ =	1.880	1.820

Fig. 15

3. With the arrangement of Fig. 13 but with potentials

unbalanced the nest cards given in Fig. 15 was obtained. The area of each card is given and an integrity table for the comparison of areas and corresponding powers is given as before. No important interference with the accuracy of the instrument was produced by such unbalancing effect. It is only necessary to secure an approximate balance, such as can easily be recognized by the eye when noting the form and location of the card on the indicator screen.

OTHER TRIALS

1. In Fig. 16 is given a nest of cards formed by the core loss of a 60-kilovolt, 20-kw., transformer supplied from the high-tension side.

2. The indicator accords means for the detection and approximate measurement of extraordinarily small amounts of power. The card in Fig, 17 was produced by an e.m.f. of 83 volts applied through *three megohms* or .0023 *watts.* The e.m.f. applied in the velocity condensers was 172 volts and the total source e.m.f. was 191 volts. In high-tension work where the multiplying displacement condensers would be used this corresponds to 2.3 watts at 191,000 volts. The loading resistances in this case were a pair of lead pencil " marks " about 5/16 in (7.938 mm.) wide and 8 in. (20.32 cm.) long made on linen writing paper. Their combined resistance when impressed with 108 continuous volts was determined by direct current voltmeter and portable galvanometer to be 3,000,000 ohms. Each of the pair of velocity condensers was made by laying an 8½-in. by 11-in. (21.59-cm. by 27.84-cm.) sheet of common typewriter linen paper as the dielectric upon a ground plate for one electrode and the other electrode was made by placing on top of the sheet a piece of tin foil 7-in. by 9-in. (17.78 cm. by

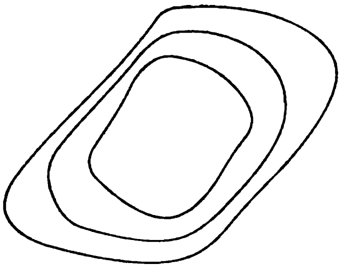
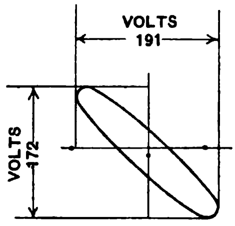


FIG. 16



AREA MEASURES .0023 WATTS

FIG. 17

22.86 cm). The limit of sensitiveness is attained only when the current-velocity quadrants of the indicator are made to serve as the velocity condensers. When that is done the sensitiveness of the instrument is such as to permit the detection of extremely minute powers, viz.:

3. As already stated for these trials, on purpose, no special care was taken in forming, mounting and insulating the quadrants. They were held in place on the glass of the tube by means of rubber bands.

Naturally according to weather conditions, the outer glass surface would collect some moisture and become conductive. When in this condition it is always interesting to apply alternating pressure to one pair of quadrants, with the remaining pair disconnected and to watch the drying off process that followed. It would be completed in perhaps a second. At the start off there would be formed a considerable card area due to displaced electric fields set up by leakage current from the charged quadrants that had an in-phase power component because of the resistance of the leakage path. The generated heat would evaporate the moisture at a rapid rate and the card areas would diminish correspondingly until after a second or so nothing remained but the right-line band due to the applied pressure. The amount of power indicated in these cases was extremely small.

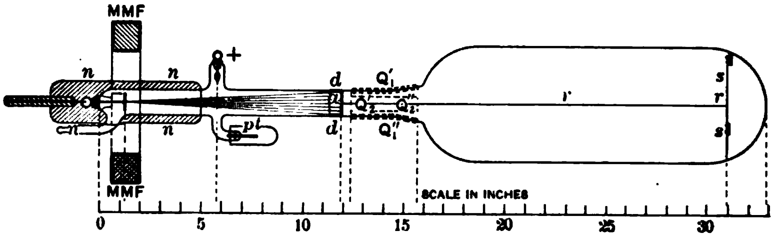


Fig. 18

It follows, therefore, that by proper refinement the indicator may be relied upon to detect the extremely small stray losses that are often responsible for serious damage to insulation.

Structural Details.

A drawing to scale of the cathode ray tube used as an electrostatic power indicator in these trials is given in Fig. 18. In view of the fact that there is no general familiarity with the source and character of the apparatus it may be well to add that this tube is made and marketed by Richard Müller-Uri of Braunschweig, Germany, catalogued by him as " Braun-Ryan No. 2761 " and sold in Germany for twenty dollars.

A cone of cathode rays, *c r*, is emitted from the disk-shaped negative electrode. At the aperature, *a*, in the aluminum diaphram, *d*, a conical pencil of these rays, *r*, is allowed to pass, striking the screen, *s*, causing a fluorescent spot of light. These rays can be concentrated at the aperature, *a*, and focussed on the screen, *s*, to a marked degree by means of the magnetic field set up by the continuous current circulating in the coil m.m.f. The coil should have proportions somewhat as shown in Fig. 18. It should have a continuous, maximum m.m.f. capacity of about 2500 ampere-turns. To begin with, the central plane of the coil should be at right angles to the axis of the tube and near the negative electrode disk. The coil should be given a mounting capable of universal adjustment so that its own field and the earth's field or any stray field combined can be made to have the proper relation to the ray-pointer so as to give the best focussing effect. The continuous current through the coil must be adjustable by rheostat initially over a wide range, producing a corresponding variation of the m.m.f. of the coil from 1,000 to 2,000, more or less, ampere-turns until by trial the best focussing value is found.

The principle upon which this focussing effect of the magnetic field depends is interesting. The flying electrons that constitute the cone of rays that emanate from the cathode, being electricity in motion, constitute electric currents and are acted on as such by the magnetic field. If the rays were parallel and not divergent they would pass through a magnetic field, in a direction parallel to the tubes of force undisturbed. Being divergent, they have a component motion at right angles to the magnetic field and behave just as electric currents at right angles to such field. The consequence is that every electron having a divergent path through the magnetic field is continually deflected by the field at right angles to the divergent component of its motion. The effect of the magnetic field is thus to whirl the electrons in circles, which when combined with linear motion imparted by the charged cathode, produces as a net result, spiral motions. By properly adjusting the position of the magnetizing coil and the amount of its m.m.f., it is practicable to make each electron describe a spiral which, in projection, appears somewhat as that drawn in Fig. 19.

By this means many more electrons are made to pass through the aperature, *a*, and to strike the same luminescent spot on the screen, *s s*, than would otherwise be the case. The spot or trace made by the ray-pointer is, therefore, much brighter than it would be without the use of the focussing coil. For the rays near the center of the ray-cone there is little or no divergence; away from the center there is more divergence. From the nature of things, this method of focussing can be made true but for one degree of divergence; it follows, therefore, that while it is effective in increasing the brilliancy of the ray-pointer and in lowering the potential at which the electrostatic machine must operate to produce the discharge, it cannot be effective to prevent materially the increase of the diameter of the luminescent spot which is always from two to three times the diameter of the aperature. Nevertheless it is a great help and should always be used[3]. The nest of power cards in Fig. 13 is reproduced at about two-thirds of the size of the originals as they appeared on the screen of the instrument. The little circle at the center is a trace of the outer circumference of a well focussed luminescent spot that produced the cards and which were recorded by tracing on smoked glass *to the center* of the band-diagram formed by the rapidly moving luminescent spot.

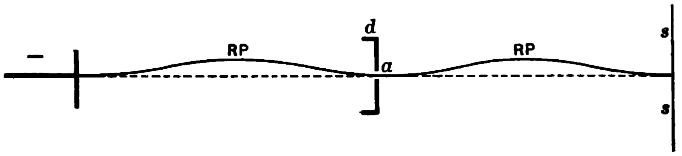


FIG. 19

The most important structural feature is the manner of connecting the negative electrode to the electrostatic machine. Ordinary good quality automobile high-tension ignition cable does very well for this purpose. Near the tube the ignition cables should be terminated by brass hooks in the manner shown in Fig. 20; and the connection should be remade

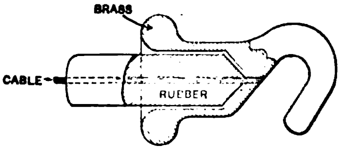


FIG. 20

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[3] Physicists have long known the general behavior of a cathode ray in a magnetic field. The author is indebted to Mr. Robert Rankin for the practical development of this system of focussing the cathode ray-pointer. Through much originality and enterprise, it was worked up by him as a graduate student in 1905.

pair of by linking the hooks. Electrostatic machines of the influence type, have a way of starting off in an uncertain direction. The hooks provide a simple, satisfactory means for reversing the connection. A photograph of the indicator showing the ignition cables joined by means of these hooks is reproduced in Fig. 21. It is important that all external edges of these hooks should be formed with an ample radius of curvature so as to prevent atmospheric conduction or corona loss discharge from the electrostatic machine. Such loss when it does occur is fitful, and gives rise to an irregularly sustained ray-pointer.

FIG. 21

The cathode terminal has a great tendency to produce atmospheric conduction right at the point where it enters the glass due of course to the high capacity of the glass which concentrates the field through the air films in that region to their breaking point, producing corona and in consequence an irregularly delivered ray-pointer. To prevent this an ample insulating jacket must cover properly the cathode end of the tube and the connecting cable as shown by cross section at *n n n n* in Fig. 18, and again by photograph in Fig. 19. The result of much experience with these jackets has been to determine that they are best made of paraffin, laid on hot by means of a brush, layer upon layer. It takes about two hours to build up the jacket in this way and when done, it is satisfactory and will last for months. After the operation is well under way the process can be hastened by sticking on pieces of glass tubing or good quality sealing wax and by pouring the well dried-out paraffin at a temperature that is just high enough to secure ample fluidity, into a paper mould formed about the part of the jacket already in place. Experience in casting the jacket complete in one operation has not been satisfactory.

When one of the tubes is used steadily a few hours daily for several months the " hardening " effect arrives that is known to all familiar with the X-ray tube. This is due to the increase in the vacuum produced by much use. When the vacuum is too high, the tube does not work so well, chiefly because of external corona loss,—besides it is liable to puncture. To lower the vacuum a small platinum tube, *p t*, Fig. 18, is sealed into the cathode ray tube at one end; the other end projecting outward is closed. By osmosis a little hydrogen may be passed through the platinum tube to the interior of the cathode ray tube when heated to red heat in an alcohol flame. The alcohol vapor conveniently furnishes the hydrogen. Care must be used not to admit too much hydrogen and thus lower the vacuum too much. The best gauge of the degree of vacuum is the electric pressure required to set up the cathode ray-pointer. The discharger balls on the electrostatic machine are conveniently employed for this purpose. A spark at ⅜ in. (9.525 mm.) gap or a little less between the discharger balls is a measure of a degree of vacuum that always gives excellent results. The balls are fixed firmly at ⅜ in. (9.525 mm) separation, so that in attempting to operate a hardened tube the machine will discharge at the balls and not through the tube. The alcohol flame is then applied to the platinum tube until it is red hot and immediately removed to await the effect. A little time should be allowed for the newly admitted hydrogen to disseminate throughout the tube. In a minute or so, if the sparks have not ceased between the discharger balls, a little more hydrogen should be admitted by reapplying the alcohol flame to the platinum tube, stopping the process each time, early, to note the result,—and so proceeding until the vacuum is lowered to the desired point, the ray pointer has been reëstablished and the sparks between the discharger balls have ceased.

A record may be made of the diagrams indicated on the screen of the instrument by photography or by hand tracing, either from the front or back of the screen. From the front the view is necessarily at an angle. Distortion is avoided by fixing the plane of the recording plate or sheet parallel to the plane of the instrument screen. The most convenient method that experience thus far has developed is to use a lightly smoked glass mounted on a small table or hand rest next to the body of the tube which must be mounted as shown in Figs. 21 and 22. A peep-sight as there shown fixes the point of view. The little table is made in the form of a shallow oblong box with ends opened and lined with white paper. At the middle an opening is cut and arranged so that the smoked glass can be mounted on the under part. Thus light can be admitted from incandescent lamps at the ends so as to shine on the point of a marking

FIG. 22

stick to assist the eye in making the record. Many methods are available for making these records including the use of the pantagraph, planimeter, etc.

As to the electrostatic machine: Any good make of Wimshurst type electrostatic machine, having four or more pairs of plates, 15 in. (38.1 cm) in diameter or larger, of hard rubber, glass or mica, will do very well.

For work in the daylight it will be necessary to exclude the light very largely from the instrument and recording table. This may be conveniently done by means of a cloth hood held in place at the top by a drawing-in tape, parted and closed with hooks and eyes, furnished with openings to admit the ends of the recording table and a sleeve to admit the recording arm of the observer, as shown in Fig. 22.

As already referred to: it is best to cover the electrostatic machine with a grounded metal net so that stray fields from the high-tension circuit will not interfere with its work. It is best to look carefully to the setting of the instrument or to protect it by grounding metal nets, so as to relieve it from interference from the same cause. Again it is well to keep the ignition cables that connect the instrument to the electrostatic machine free from vibrations because the stray field they carry will correspondingly sway the position of the ray-pointer; or better, their stray field may be shut out also by means of a properly mounted metal grounded net.

THE CATHODE-RAY POWER DIAGRAM INDICATOR OPERATED AS AN OSCILLOGRAPH

It is often desirable to know the wave forms of the e. m. f. or current employed in the high-tension insulation tests or other work for which the electrostatic power indicator may be employed. This is easily accomplished for the e.m.f. wave by short-circuiting out the indication of the current-velocity field. The ray-pointer then has simply a displacement motion that is proportional to the e.m.f. from instant to instant. The wave form drawn in the familiar rectangular components may be viewed through a synchronously revolving mirror such as is employed in connection with the common Dudell type of oscillograph. Or it may be made to trace its time card by applying a sine-wave pressure tapped from a sine-wave current source[4] to the current-velocity quadrants. As the

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[4] The Cathode Ray Alternating Current Wave Indicator, by Harris J. Ryan. TRANSACTIONS A.I.E.E., Vol. XXII, p. 539, 1903.

third harmonic is almost invariably absent from the ordinary three-phase source, pressure tapped from one of the phases of such a source will be approximately sine-wave, and may be applied to the velocity quadrants in lieu of the true sine-wave pressure to develop the oscillogram of the e.m.f. where great refinement is not necessary.

To produce an oscillogram of the current, non-inductive resistances, having values equal to the reactances of the velocity-condensers should be substituted in lieu thereof. Deflections of the ray-pointer will then be produced that are proportional to the instantaneous values of the current. The current wave form may then be observed and recorded by means of the revolving mirror, or the current may be made to produce its oscillogram by substituting, in convenient phase, a sine-wave pressure for the line pressure that was cut off from the corresponding quadrants when the start was made to oscillograph the current. Unless the pressure necessary to actuate the ray-pointer is small compared with the total impressed pressure this method will introduce errors that are small to begin with and which increase in an obvious mannner as the difference between the two pressures grow less. This may be avoided altogether by taking an oscillogram of the current-velocity movement of the ray-pointer which will not be so easy to interpret but which will have introduced no error.

THE MAGNETICALLY OPERATED POWER DIAGRAM INDICATOR.

A number of years ago Dr. D. K. Morris at the University of Birmingham, England, by the combined action of two Dudell oscillographs, produced hysteresis cards from closed laminated magnetic circuits actuated by alternating currents. To do this the magnetizing current was passed through one oscillograph and through the other a current was passed that was generated by a secondary coil mounted over the closed magnetic circuit and controlled by an inductance, as pure as it is practical to make. The ray-pointer of light was reflected from the mirror of one instrument and then from that of the other by a suitable arrangement of optical facilities so as to trace on the observing screen or recording plate a card of the hysteresis present in the closed magnetic core.

It is easy to perform this same experiment by means of the magnetically operated cathode ray oscillograph. One instrument does the work because the cathode ray pointer will at once follow both rectangular displacements, one proportional to the magnetizing current and the other proportional to the core-flux present. This was done in the Cornell laboratories for purposes of instruction in 1905. It was not recognized, however, at the time that such an instrument is inherently a power diagram indicator and that it behaves as such *when connected as in Fig.* 23.

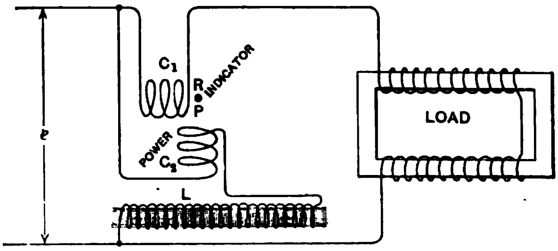


FIG. 23

The theory of this indicator is precisely the same as that for the electrostatic type except that magnetic fields are used in lieu of electric fields, and current and e. m. f. have exchanged duty in producing the displacement and velocity movements of the ray-pointer, *i. e.* in the magnetic power indicator the ray pointer is given a displacement that is in proportion to the line current and a quadrature velocity that is proportional to the impressed e. m. f. for a current that is controlled entirely by

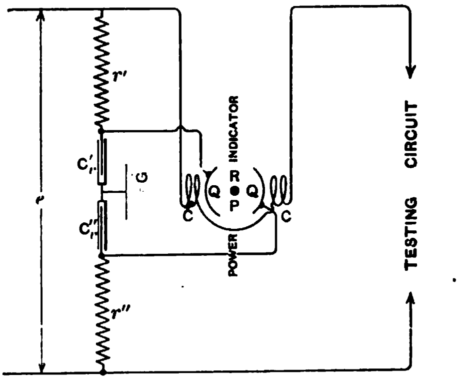


FIG. 24

inductance varies at a rate that is proportional to the impressed e. m. f., or

$$e = \frac{d\,i}{d\,t}$$

Finally it is apparent that a combination static-magnetic power diagram indicator should be possible and practicable. One such form that has suggested itself is shown diagramatically in Fig. 24 wherein the reactance of the pressure velocity condensers C_v' C_v'' must be small compared with the value of the non-inductive, noncondensive controlling resistances, $r'\,r''$.

This investigation was undertaken to provide a satisfactory electrostatic power diagram indicator to be employed to detect and measure stray power losses that occur in and often injure dielectrics employed in high-tension practice. There was no thought to produce a corresponding magnetic form of instrument. It came along with the undertaking as a sort of by-product and as yet no important need of it has been discovered. Doubtless in time it may prove to be of particular value in certain classes of work.

The author is happy to employ this opportunity to acknowledge his indebtedness to his co-workers, Professors S. B. Charters, Jr., and W. A. Hillebrand, for their hearty coöperation in making the trying out experiments herein reported and to the authorities of Leland Stanford Jr. University who approved the purchase of the equipment required for work of this character.

DISCUSSION ON "A POWER DIAGRAM INDICATOR FOR HIGH TENSION CIRCUITS," LOS ANGELES, CAL., APRIL 27, 1911.

E. F. Scattergood: I understand that this instrument is quite easily moved and therefore available for investigations in the field and I would like to hear something further in regard to the portability of the instrument. I feel that the profession is greatly indebted to Professor Ryan for the instrument which he has developed and presents as well as for the practical results he has secured from its use and presented by him last January.

C. L. Cory: I think you will agree with me that as Professor Ryan outlined to us the details of this instrument we enthusiastically admired the manner in which the result has been accomplished. Professor Ryan stated that in general the measurement of one watt at 100,000 volts is of little consequence in the practical operation of transmission systems. However, we are interested quite as much in being able to measure the indefinitely small quantities here indicated as we are in the accuracy of the measurement of the quantities ordinarily of interest in such systems. In his experimental work he has measured power at 9,000 volts amounting to only 0.03 of a watt. This would correspond at unity power factor with a current of 1/300,000 of an ampere. We are with this instrument capable of measuring the three hundred millionth part of the output of a modern 3,000 kilowatt steam turbine alternator, and it is quite as important sometimes to be able to measure these very small quantities as it is to accurately measure the larger quantities.

The instrument allows a beautiful analogy to the steam engine indicator. We have a horizontal line on the bottom which corresponds to the line of atmospheric pressure. We have a vertical line which corresponds to the variation of pressure. In Fig. 7, where the pressure approaches 40,000 volts, the diagonal line shows no energy. Beyond this the two areas, one larger than the other, indicates at which point the " thing turns around the corner ", so to speak. The instrument is one which it seems to me will have wonderful practical application. We have had indicated to us directly how insulators may be tested and I dare say we might quite as well use it to determine the dielectric constant of condensers. It is applicable to ordinary voltages quite as much as it is to our highest practical voltages. After all, that which is probably the greatest attainment, however, is the beautiful and accurate method whereby it is possible to measure accurately on the very highest voltage systems the smallest possible quantities and in addition to ascertain what is happening on the line as a result of the action of such small quantities of energy.

J. J. Frank: I see practical value in the use of this instrument in measuring losses at high potentials. At present we have no satisfactory means of measuring such high potentials because our instruments do not follow the variations in the wave-shapes of potentials. The only instrument we have is the spark-gap.

If this instrument of Professor Ryan's does recognize the wave-shape, it will certainly be of value in measuring losses on lines, in cables, dielectrics, oil and insulators, which is one of the important studies we now have before us in connection with high voltage transformers.

Ralph D. Mershon: Professor Ryan spoke in a very off-hand way of getting a known high voltage load with which to calibrate his instrument. I have often endeavored to get such a load that would be above suspicion, but have never succeeded. If Professor Ryan has devised some means of getting a high voltage load that will remain constant, and can be accurately measured, I shall be glad if he will tell us of it.

I should like to ask Professor Ryan whether he has investigated, by means of this instrument, the effect of moisture on the corona.

I desire to take this opportunity of expressing my appreciation of this paper, and my admiration for the work it evidences. With Professor Cory, I think the sensitiveness and accuracy are most astonishing, and should lead to extremely valuable results. An instrument of this sort should be well adapted to the study of insulation and what happens when it is subjected to electrostatic stresses. At the present time our knowledge in regard to dielectrics is comparatively limited. I believe one of the greatest problems before the Electrical Engineer today is the problem of insulation; that there is a possibility for great improvement over what we have now. What we would like to have, is an insulating material that can be worked like metal, and that will stand the temperatures most metals will, so that we can run our apparatus at something like the temperature of a steam engine. It seems to me, the further we get away from organic substances the more nearly will we approach a satisfactory solution of the insulation problem.

H. J. Ryan: I will take these questions up in the order in which they were given. As to the portability of this apparatus: In its present stage of development it is not very portable. An American instrument maker is now investigating it with a view to placing it on the market in a portable form should that be found practicable. In 1901 I transported an outfit of substantially this same sort from Cornell to Columbia to operate it magnetically as an oscillograph at the conversazione given by the American Institute of Electrical Engineers. In 1905 I again transported a similar, though a much more complete outfit from Ithaca to Pittsburg to deliver an illustrated lecture at the Electric Club on the uses of the cathode ray oscillograph. Those two experiences demonstrated that the outfit referred to in this paper can be considered as portable equipment, though it is certainly a long way from constituting a portable instrument in its present form, I began ten years ago to look for a feasible electrostatic power diagram indicator. My great regret now is that largely through a feeling that such a thing was perhaps impossible, I failed to realize that I had at hand all the while the necessary expedients. These were employed just as soon as the principles were worked out upon which the power diagram indicator must operate.

Referring to Mr. Frank's question as to whether this instrument will recognize wave forms—it will do that very nicely. Alternating voltage applied between one pair of quadrants only will cause the ray-pointer to oscillate and the true voltage wave form may be observed by looking at the band of light thus produced on the screen. To do this transmit the image of the moving spot to the eye through the usual synchronous vibrating mirror. If preferred the ray-pointer may be given a sine-wave motion in quadrature with the motion imparted to it by the voltage. Thus an open card is formed of a known and an unknown motion. In that way the unknown voltage wave form that imparted the corresponding motion to the ray pointer becomes known. We can all realize this by remembering the steam engine indicator card. There the horizontal motion being reduced from the piston motion is known. The vertical motion produced by the steam pressure is unknown until the indicator card is produced by combining both motions when it is made known also. A sine wave current for this purpose is obtained by means of a " wave filter " described in my paper on the cathode ray oscillograph read at the 1903 Niagara Falls meeting. The ray-pointer is actuated magnetically by such current. If you are making accurate measurements of this kind, you would have to go into a careful arrangement of the electrodes mounted on the walls of the tube in order to make the spot deflect accurately in all regions; that is, to make the quadrature deflections in all regions proportional to the applied potential differences. That means not using a plate bent around the tube for the electrodes, but using parallel wires and distributing them around the tube until the electric field therein is entirely uniform within the range in which you are using it. For all ordinary work the quadrant will not have to be given such special construction.

As to objection to the internal losses in the high-tension circuit of the transformer when you apply the velocity to the condensers at the center of the same, instead of at the center of the samples: If the oil is clean, newly treated, has not been in the service, you will not find a loss such as you may expect. If, however, the transformer is not in this condition, *i.e.*, the oil has not been treated and put into proper condition for a test of this kind, then you obtain an area there that, under some circumstances, I am pretty clear could be cared for by subtracting; but it was on that account that I went after this method of using the sample itself only that is by working at the center of the sample. (See Fig. 8.)

Replying to Mr. Mershon's question as to what extent we may use this instrument for measuring high-tension line losses due to inphase current through the atmosphere—*i.e.*, corona formation.

We made some use of the instrument for corona loss measurements and have found that it does very well for such purpose. Measurements of sub-corona atmosphere line losses are difficult always because of the low power factor present. The instrument as it stands in this paper is at a corresponding disadvantage. When the power factors are small, one to two per cent, for example the corresponding power card is inconveniently elongated. To obviate this difficulty we have tried out an arrangement of velocity condenser that makes use of some of the line voltage for compensating the elongating effect of the reactive power. We found that this can be done and that wider cards can thus be obtained to indicate losses that occur at very low power factors and which otherwise would produce long narrow inconvenient and correspondingly inaccurate cards.

As to the axes not being at right angles in Fig. 6, that is due to the fact that our original try-out tests were just to see whether the thing would work. This was all done last spring. If we had had any notion in advance that the method would have worked out in this way, we would have taken a little more care. The quadrants were held to the outer walls of the tubes by rubber bands; they did not produce electrostatic fields that are exactly at right angles to one another because no effort was made to adjust them with exactness. These try-out integrity tests were made with this careless mounting of the electrodes, for the reason that I thought the apparatus would go into use, if at all, as something that we could bring together with comparative ease. As a matter of fact, it turned out much better in this respect than was anticipated. I did not have the time to make special tests for this paper, but took the tests which we had made in our former work. They are just as they were made in the original trials when we undertook to see how the method would work.

C. L. Cory: I would like to ask Professor Ryan if the fundamental work has not already been done to a sufficient degree so that we may very properly anticipate the use of this instrument, properly installed in commercial shape, in a substation for instance, so that experiments may be made on long distance transmission systems at different frequencies from 20 to 60 cycles and at different voltages from perhaps 30,000 up to 150,000 volts, not only on transmission lines which are practically level but on those crossing mountain ranges in which the different parts of the line are subject to atmospheric conditions which vary with the altitude.

What I am trying to bring out is the practicability of the instrument to determine questions not heretofore capable of satisfactory treatment.

Is it not true that the results to date indicate the possibility of the use of the instrument permanently installed in a substation for experiments on long lines in place of the one only 100 feet in length as used in your laboratory.

H. J. Ryan: I think that can be done. I believe, for my own part, it will be reduced to such convenient form.

R. W. Sorensen: Am I correct in my understanding that with an arrangement such as is shown in Fig. 23, the indicator can be used for measuring the core loss occurring in the transformer shown as load.

H. J. Ryan: The method given in that figure is for low-tension work entirely and it was put in here to round out this general scheme. If you can get a proper inductive control of the current in the circuit " L " then the area of the card should be proportional to the power that is applied to the circuit. The ray-pointer will then have a velocity proportional to pressure and not proportional to current; and it will have a displacement proportional to current.

R. W. Sorenson: In Fig. 8, for instance, the sketches marked " T ", etc., I presume are parts of a transformer.

H. J. Ryan: That is correct.

R. W. Sorensen: Would you measure on the transformer the loss due to the dielectric hysteresis, if the pans containing the oil sample were removed?

H. J. Ryan: If the sample were disconnected the ray-pointer would be given no velocity displacement, it would have a pressure displacement. A band of light would be formed on the screen due to such displacement being proportional to the terminal voltage of the transformer.

R. W. Sorensen: Then in Fig. 4—what would we get there, that we would not get with connections like Fig. 8, with the sample pans of oil left out.

H. J. Ryan: In Fig. 4 with no test specimen or other load connected the ray-pointer would be given a velocity movement proportional to the internal capacity charging current of the transformer and it would be given a displacement at right angles to such velocity proportional to the transformer terminal voltage. The result would be a card that would constitute a certain kind of measure of the high voltage dielectric loss in such transformer.

R. W. Sorensen: The reason I asked these questions was that about two years ago I tried to find out what was happening in a high voltage transformer. That is, it seemed to me, according to some work we had, that there is always a certain amount of energy transmitted through the dielectric. In some instances, it does not amount to much. In the case I have in mind the transformer happened to have four sections. When those four sections were in series, there was three to five per cent more core loss by test than when those windings were broken up in sections. I said the greater part of that must be dielectric hysteresis loss. What I am getting at is, can we measure with your instrument the dielectric hysteresis loss only and thus eliminate the error of subtracting one large quantity from another to get a small one as was done in the test to which I refer?

H. J. Ryan: If you lay the case of the transformer open, even in the California climate during the summer, it will show you, in a hurry, a nice fat card.

R. W. Sorensen: But it measures only the hysteresis loss; and not any other losses?

H. J. Ryan: Yes, it measures only the dielectric hysteresis loss. Certainly such is the case after subtracting the $I^2 R$ loss that occurs in the high tension winding due to the circulation of the internal capacity charging current. Unless the oil is in the very best possible condition such dielectric loss, we have found may be considerable.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 27, 1911.

THE USE OF POWER-LIMITING REACTANCES WITH LARGE TURBO-ALTERNATORS.

BY R. F. SCHUCHARDT AND E. O. SCHWEITZER

INTRODUCTION

In large electric power systems the maintenance of a very high degree of reliability, that is, continuity and uniformity of service, must be the constant aim and is one of the principal problems of the engineer. While the problems during the earlier years of central station work often appeared very difficult, the advent of the large capacity, high-speed turbo-generators coupled to systems containing hundreds of miles of transmission lines, made them much more complex and they took on a far more serious aspect.

The question most actively before some of the larger electric power companies at the present time is that of limiting the amount of energy which can flow into a fault. The solution in some instances of present turbo-generator installations will probably be the installation of current limiting reactances. It is the purpose of this paper to present some of the data obtained during a long series of unusual tests made during February, March and April of this year, on such reactances in conjunction with a large turbo-generator and to offer a few conclusions based on the results.

EVOLUTION OF ENGINEERING IN THE SYSTEM OF A LARGE CITY

In tracing the various steps in the evolution of the engineering with respect to provisions for safe-guarding the generating apparatus, the writers naturally cite the experience of the system with which they are most familiar, namely, that of the Commonwealth Edison Company and its predecessor companies. The troubles of the stations of the early years are quite well known and in the light of present knowledge were comparatively simple. No time will be taken in this paper for their consideration. This applies to stations down to and including the time of slow-speed alternators direct coupled to reciprocating engines and feeding a transmission system of some considerable size. It was not until the introduction of the high-speed turbo-alternators that serious troubles were experienced which indicated that these later units had characteristics quite different from those of their engine-driven predecessors.

The experience in Chicago during the past eight years, that is, since the operation of the Fisk Street Station with its pioneer 5000-kw. turbo-generators was begun, showed an increasing severity in the disturbances (due to apparatus and cable breakdowns) with the growth of the stations and, therefore, apparently due to the increase in generator capacity. This can perhaps be better appreciated when we remember that previous to October, 1903, the total capacity in high voltage alternators on the system of the then Chicago Edison Company amounted to 9800 kw., while in October, 1911, the total capacity of the three large stations will aggregate about 250,000 kw.

The original 5000-kw. generators at Fisk Street, of which there were four, had their neutrals grounded solidly. These were all 9000-volt six-pole machines operating at 500 rev. per min. The fifth unit to be installed was of larger capacity and, having four poles, operating at a speed of 750 rev. per min. It was found that with the neutral of this fifth unit closed to ground a comparatively heavy cross current flowed between it and the other units, and a neutral resistance of approximately 2½ ohms was installed on the new unit. This resistance incidentally served to limit the current which would flow into grounded apparatus or cable (" Y " pressure of the generators is 5200 volts). All additional units were, therefore, provided with neutral resistances and later the solid connections to ground of the four original units were removed. To further limit the current flowing into a single-phase fault, the neutral was closed on only one of the units operating on the system. With the continually increasing capacity the exact effect of these various changes could, of course, not be determined, as breakdowns in apparatus or in cable do not occur with great frequency and in most cases the conditions are so involved that the effects cannot be accurately analyzed. It is easily seen, though, that these various steps must have served to reduce the energy flowing into a single phase fault.

Disturbances were, however, still of sufficient severity occasionally to have a widespread effect and the system was, therefore, divided into sections so that a fault was reduced in severity and limited to one section, leaving the remainder of the system undisturbed. This was going back in part to the original method of operating this station, each unit initially having fed only its own lines independent of the other units. The maximum capacity now permitted on each section was set at 50,000 kw. Even with these precautions, however, severe disturbances occurred and especially at times when the generator armatures themselves developed faults. In the four years from 1906 to 1909 inclusive, there were seven generator burn-outs, all of which caused a temporary shut-down of part or all of the substation apparatus on the section to which the particular generator was connected. The storage batteries, of course, meanwhile maintained the service in the direct-current districts. In practically all of these cases the armature end turns were torn loose and the windings were pretty well wrecked. It was then appreciated more strongly than ever before that a more rigid construction of the generator was necessary and the armatures were rewound with a new form of coil with a very much improved arrangement of end turns; also, one coil was laid in a slot instead of two, as in the former winding. The experience thus far apparently indicates that this improvement is satisfactory. With severe short circuits the switches continued occasionally to give considerable trouble and in one or two instances actually failed.

On the 20,000 volt system fed normally through two 5000-kw. transformers from the 9000-volt system which transformers originally had a reactance of approximately 2½ per cent, cable breakdowns in four instances caused disastrous results within the transformer, completely wrecking part of the winding.

NEED FOR INCREASED REACTANCE

The absolute necessity for reducing the current which can flow into a fault was now very clear. As this current is a function of the reactance of the circuit it was apparent that the reactance must be increased. The transformers were rewound in a manner to give an internal reactance of approximately 4½ per cent. An additional amount could be added externally. In the case of the generators the higher value of reactance could, of course, be taken care of in new designs. In new units of very large capacity it was thought best to divide the desired total reactance between the generator itself, winding it for comparatively low voltage, and an auto-transformer which would serve to step up the voltage to the required value. The major duty of withstanding the shocks caused by system disturbances, was thus placed on a device external to the generator. In the case of existing units the additional reactance could best be supplied by the use of external coils which would serve also as a buffer against potential risk and relieve the generator of excessive short circuit strains. The installation of an induction generator would have introduced numerous complications and was, therefore, not considered.

REACTANCES FOR TRANSFORMERS

For the transformers above mentioned, further additional reactance was provided in the form of external coils of approximately 4 per cent reactance (that is, designed to absorb 4 per cent of the " Y " voltage at full load current). These were connected in series on the primary or 9000 volt leads. They have now been in service nearly two years and during that time the transformers have successfully withstood a number of short circuits of a kind which previously had caused them to be wrecked.

REACTANCES FOR GENERATORS

In the case of the generators the installation of reactances presented a far more serious problem. There was a natural hesitancy at the beginning in installing apparatus on which so little definite knowledge was available and which required a considerable outlay of money for its installation. In order to house the coils at Fisk Street, for instance, an addition was required along the entire length of the switch house, while at Quarry Street where there are four 25-cycle units of 14,000-kw. capacity each, part of an excitation storage battery had to be moved and material structural changes made to provide the necessary room.

PURPOSE OF AND PREPARATION FOR TESTS

In view of the large investment required and the possible hazards that might result, it was deemed desirable to learn more about the actual behavior of the proposed coils and their effectiveness toward the desired results before proceeding with their installation and for this purpose an elaborate and very complete series of tests was conducted, using one of the 12,000-kw., 9000-volt, 25-cycle turbo-generators at the Fisk Street Station.

All conductors of this unit, that is, armature and field leads and all meter and control wires, were disconnected from their regular service and connected temporarily to points outside of the station. A section of the basement at the end of the building was partitioned off and the reactances were installed therein. A temporary structure was erected in the yard outside of the station building and in this were placed two oil switches, one for making the short circuit on the 12,000-kw. unit and the other for opening this short circuit. The very unusual opportunity offered for studying the action of oil switches was taken advantage of and a number of tests were made on such switches, the results of which are presented at this Convention in a paper by Mr. E. B. Merriam.

One end of a construction shop located in the yard about 50 ft. from the oil switch structure and from which a full view of the switches was had, was temporarily converted into a control center and in this were placed two oscillographs, terminal boards for the control and meter wiring, and suitable panels carrying the switches and meters. A telephone system was installed between this temporary control center and a convenient point in the turbine room and all the work to be done by the large number of attendants and observers was thoroughly organized so the tests could be made safely and expeditiously.

The points to be determined by the tests were the following:

1. The instantaneous short circuit current of turbo-generator without external reactance.
2. The instantaneous short circuit current of turbo-generator with an external reactance of 4 per cent.
3. The instantaneous short circuit current of turbo-generator with an external reactance of 6 per cent.
4. Duration of the transient phenomena incident to the short circuits under conditions 1, 2 and 3.
5. The effect on the generator of these short circuit currents.
6. The behavior of the reactance coils.
7. The effect of the installation of reactance coils on the stability of the system.

DESCRIPTION OF APPARATUS TESTED

The unit selected is turbo-generator No. 10 and is shown in Fig. 1. The generator has a " barrel coil " winding made up of 36 coils, four turns per coil, laid in 72 slots. The resistance of the armature per phase of the " Y " winding is 0.0244 ohms at 25 deg. cent. From calculations made to determine the armature impedance, it was found that this is approximately 2 per cent. This value, however, does not include consideration of transient constants and the effective reactance at time of short circuit is in excess of this value due to several causes chief of which is the rapid dying down of the field, as is clearly brought out in the data presented. The full load current is 770 amperes. Fig. 2 shows a view of the armature winding, the field being removed, and incidentally illustrates the new form of end turn construction.

Fig. 1

The field is of the indefinite pole, laminated core type. Its resistance is 0.238 ohms at 25 deg. cent. measured from the terminals at the collector rings. The full load excitation with unity power factor is approximately 400 amperes. Fig. 3 shows the field. The ends are shown covered with boiler plate. The winding can, therefore, not be seen except where it passes the air ducts.

A set of three reactance coils, one for each phase, was used. This is shown in Fig. 4 and was designed for a reactance voltage at 25 cycles of 312 per coil (6 per cent of the Y voltage) with a current of 770 amperes. Each coil has 76 turns of 1,000,000-cir. mil cable wound on a hollow concrete core having no iron in any part. The inner diameter of the turns is approximately 2 ft., 10 in., and the outer diameter about 4 ft. 3 in. The inner layer has 26 turns, the middle has 24, and the outer layer 26 turns. The vertical distance between turns is three in. and the horizontal distance between layers is 2¼ in. The diameter of the copper is approximately 1$\frac{3}{16}$ in. The coils used in the tests have an outer layer of ½-in. cord, as shown in the figure. This is for the purpose of preventing persons or materials coming in contact with the bare conductors. The total height of the coil structure is approximately eight ft., and the copper turns extend over about three-fourths of this height. By measurement the impedance of each coil at 25 cycles is 0.425 and the resistance 0.0075 ohms. The coils were installed six ft. between centers and anchored into the concrete floor and braced at the top by 6-in. by 6-in. oak beams, 14 ft. long. The clearance between copper of adjacent coils was 27 in.

FIG. 2

The connections were made as shown in Fig. 5.

DESCRIPTION OF TESTS

The short-circuiting switch was closed in all cases with the generator at full speed. A total of 167 short-circuit tests were thus made of which 88 were at full voltage, 38 at one-half to full voltage, and 41 at less than one-half voltage. With the exception of a few tests as noted in Table V and VI the neutral connection of the generator was solidly grounded throughout the series. In the case of the exceptions a 2½ ohm resistance (one of the regular neutral rheostats used at the station) was inserted in this neutral connection. Two oscillographs were used, as shown in Fig. 5, and records were obtained of various currents and pressures, as indicated below.

The initial tests were, for safety, made at low voltage and these were followed by a large number of tests under various conditions, the majority, as already stated, being at normal voltage. The principal data obtained are given below. The pressure traces of the oscillograms were obtained from the secondary of 200 watt potential transformers, ratios 100 to 1 and 120 to 1, (see Fig. 5), and the current traces from the secondaries of type S current transformers, the ratio being selected with reference to the probable primary current. To test the effect of stray field from the reactance coils upon the 120 to 1 current transformers used to get oscillograms of generator currents and

Fig. 3

which were placed about six feet from the reactances, a 400 to 1 current transformer was installed on the *A* phase of the armature leads on the turbine room floor at least 30 ft. from the reactances. Comparative oscillogram curves are shown taken from this transformer and the regular transformer. The first rush of current as shown by the two transformers checks closely, but considerable discrepancies exist in the current values during the later cycles as shown in Figs. 14 and 15. In all oscillograms except those shown in Figs. 6, 24 and 26, 400 to 1 current transformers were used instead of 120 to 1 current transformers for the traces of generator currents.

Unfortunately in mounting the oscillograms, special attention was not paid to arranging the two prints, where two oscillograms were taken at one time, so that simultaneous occurrences would appear in line. Because of the time limitation it was impossible to correct this before the illustrations had to be sent in for reproduction. However, the simultaneous sequence of events is so clearly shown that the occurrences can readily be studied with relation to each other. In all cases the sequence of events illustrated on oscillograms is from left to right and in the identification marked below the curves, the traces are read from top to bottom. In connection with the study of the various waves it should be stated that the absolute phase rotation of the system is in the direction C. B. A.

FIG. 4

Considerable data can be obtained from these oscillograms which are of great value and interest in the study of the charac-

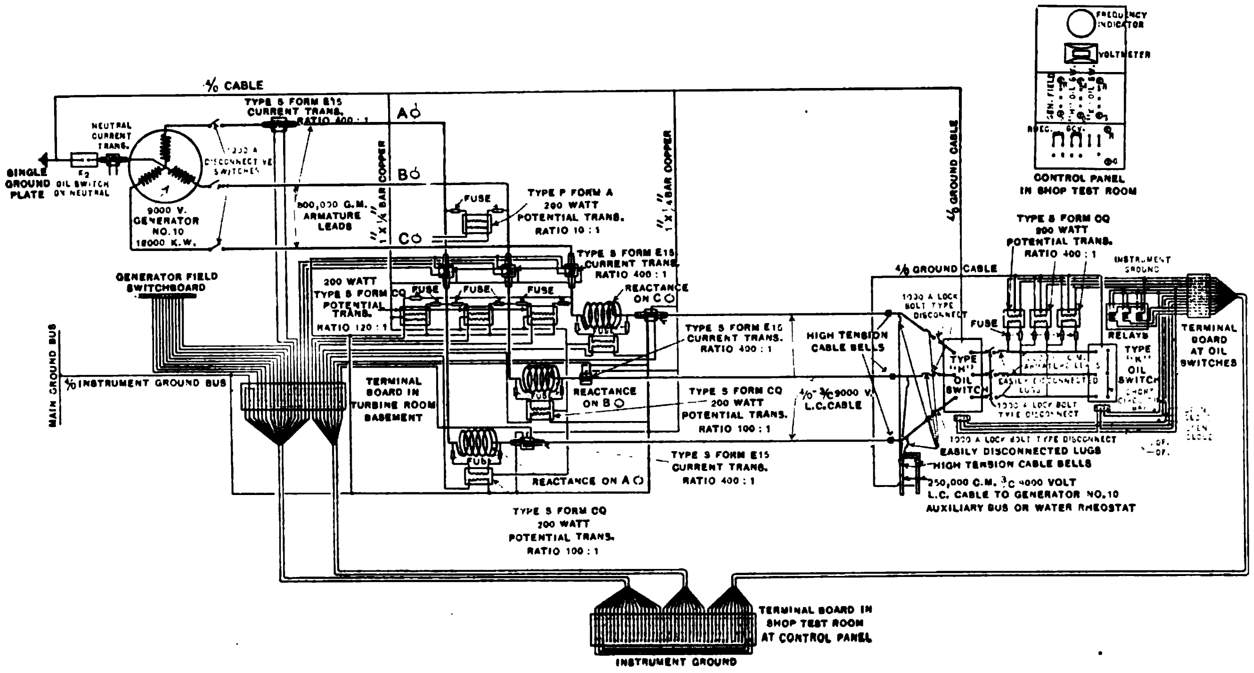
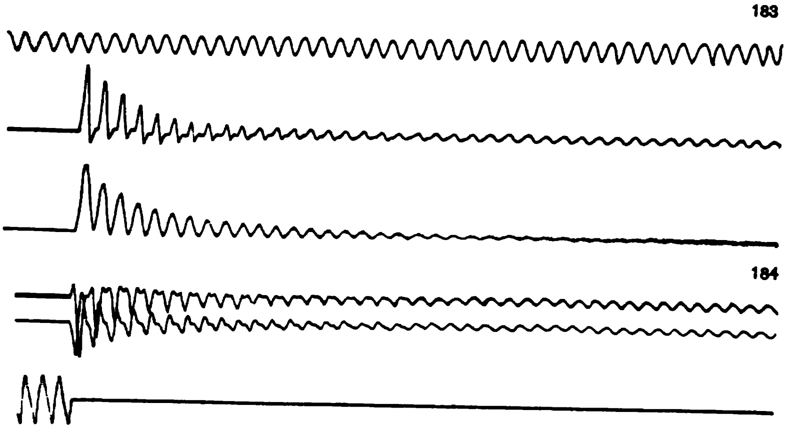

4/0 CABLE
SINGLE GROUND PLATE
E2 OIL SWITCH ON NEUTRAL
NEUTRAL CURRENT TRANS.
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
1200 A DISCONNECTIVE SWITCHES
9000 V. GENERATOR NO. 10 18000 K.W.
800,000 C.M. ARMATURE LEADS
1" x 1/4" BAR COPPER
A
B
C
FUSE
TYPE P FORM A 200 WATT POTENTIAL TRANS. RATIO 10 : 1
1" x 1/4" BAR COPPER
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
200 WATT TYPE S FORM CQ POTENTIAL TRANS. RATIO 120 : 1
FUSE
FUSE
FUSE
REACTANCE ON C
GENERATOR FIELD SWITCHBOARD
MAIN GROUND BUS
4/0 INSTRUMENT GROUND BUS
TERMINAL BOARD IN TURBINE ROOM BASEMENT
REACTANCE ON B
REACTANCE ON A
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 100 : 1
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 100 : 1
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
HIGH TENSION CABLE BELLS
4/0-3/C 9000 V. L.C. CABLE
4/0 GROUND CABLE
4/0 GROUND CABLE
1000 A LOCK BOLT TYPE DISCONNECT
FUSE
TYPE "H" OIL SWITCH
ARMATURE LEADS
EASILY DISCONNECTED LUGS
1000 A LOCK BOLT TYPE DISCONNECT
TYPE "K" OIL SWITCH
SHORT CIRCUITING BAR
1000 A LOCK BOLT TYPE DISCONNECT
EASILY DISCONNECTED LUGS
HIGH TENSION CABLE BELLS
250,000 C.M. 3/C 9000 VOLT L.C. CABLE TO GENERATOR NO. 10 AUXILIARY BUS OR WATER RHEOSTAT
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 400 : 1
INSTRUMENT GROUND
RELAYS
TERMINAL BOARD AT OIL SWITCHES
FREQUENCY INDICATOR
VOLTMETER
GEN. FIELD
REC.
SCV.
CONTROL PANEL IN SHOP TEST ROOM
TERMINAL BOARD IN SHOP TEST ROOM AT CONTROL PANEL
INSTRUMENT GROUND

FIG. 5

teristics of turbo-generators of the type under test but the practical bearing of some of this data is somewhat remote and because of the extreme length to which this paper would otherwise have to be carried, considerable of it is omitted. Thus for instance, the value and characteristic of the field current under the various conditions comes in this class. This and other of the data open up a vast field for study and many of the questions in connection with them would of themselves and with the test data furnish sufficient material for a long paper. Many of the oscillograms contain a trace obtained from the field current and these traces show in a general way the action of the field.



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 20,100 amperes per in.
3—Generator field current; scale 3,300 amperes per in.
4—*A* phase generator current; scale 23,700 amperes per in.
5—*B* phase generator current; scale 28,200 amperes per in.
6—*A B* generator delta pressure; scale 33,000 volts per in.

Fig. 6.—Oscillograms of a three-phase short circuit with no external reactance at 3,000 volts generator delta pressure with steam on turbines

The Tests

1. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITHOUT EXTERNAL REACTANCE

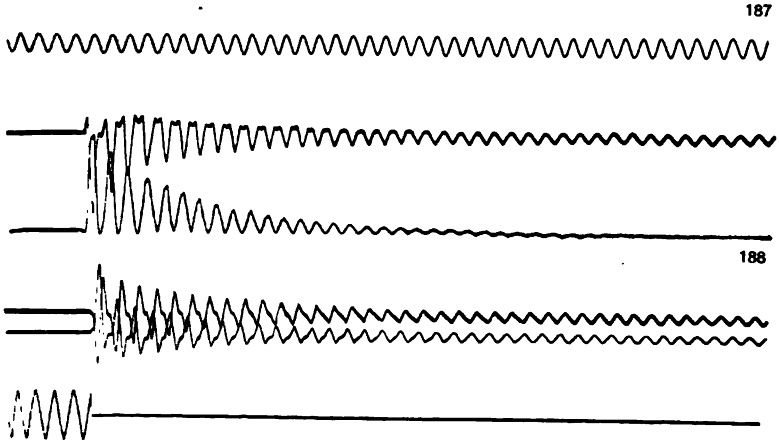
In order to determine as nearly as possible the exact effect of the reactances in limiting the energy flowing into a fault it was necessary to obtain data of turbo-generator characteristics without external coils. It was obviously unsafe to carry this to the limit of normal voltage but tests were made at voltages from

TABLE I.

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
54	137	0	H-3	3 ϕ	1000						1800	
55	139	0	"	"	1000						4550	
56	141 142	0	"	"	2000	+ 58%	— 41%	— 99%		5200	3100	
57	143 144	0	"	"	3000	+ 80%	— 11%	— 92%		9400	6100	
58	147 148	0	"	"	3000	— 99%	+ 57%	— 43%		7800	7800	
78	179 180	0	"	"	3000	+ 50%	— 50%	100%	7260	9400	6000	
79	181 182	0	"	"	3000	— 7%	— 89%	+ 82%	7100	7500	4000	
80	183 184	0	"	"	3000	— 48%	100%	+ 52%	6900	4700	6700	See Fig. 6.
81	185 186	0	"	"	3000	+ 74%	— 22%	— 95%	6700	9400	6400	Steam shut off just before short circuit. See Fig. 7
82	187 188	0	"	"	3000	+ 94%	+ 18%	— 76%	6000	10000	8240	
83	189 190	0	"	"	3000	— 98%	+ 66%	— 32%	5760	8940	9000	
84	191 192	0	"	"	4000	— 87%	+ 87%	0%	9230	8800	7600	
85	193 194	0	"	"	4000	— 33%	— 98%	+ 65%	9720	7700	7360	See Fig. 8
86	195 196	0	"	"	4000	— 39%	— 99%	+ 66%	9920	8800	8500	Steam shut off just before short circuit. See Fig. 9
87	197 198	0	"	"	4000	+ 87%	— 87%	0%	9520	7460	9900	
88	199 200	0	"	"	4000	+ 58%	— 41%	— 96%	9720	12200	8200	
89	201 202	0	"	"	4000	+ 99%	+ 40%	— 59%	7200	11850	11300	See Fig. 10

+ Represents increasing wave. — Represents decreasing wave.

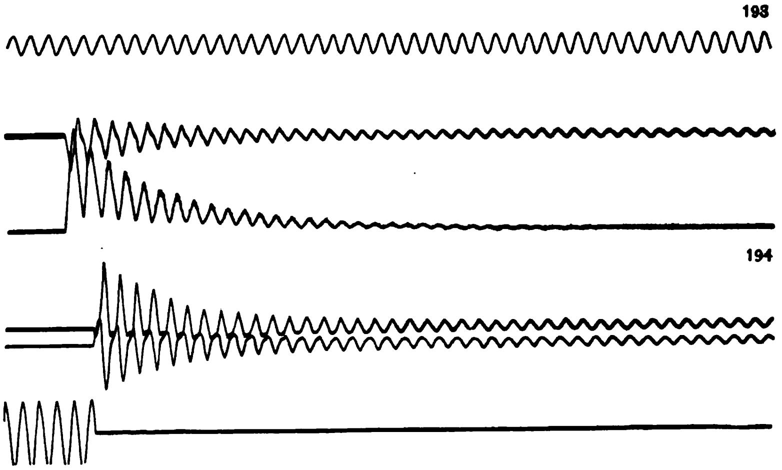
1000 to 4000. Data of seventeen of these tests are given in Table I and the principal characteristics are illustrated in Figs. 6 to 10 inclusive. A time reference wave taken from the 25-cycle system was used to determine the retardation of the turbine but these traces show no appreciable retardation within the time covered by the film. In later tests with a slower speed of film revolution a retardation of ¼ cycle in five seconds was found. The values of current and pressure of these oscillograms are given in the table. The maximum field current shown in Fig. 6 had a value of approximately 1200 amperes; in Fig. 7, 1740 amperes; in Fig. 8, 1850 amperes, in Fig. 9, 2000 amperes and in Fig. 10, 2400 amperes. The various data regarding the condition of the field circuit are omitted for reasons given in preceding paragraph.



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 20,100 amperes per in.
3—Generator field current; scale 3,300 amperes per in.
4—*A* phase generator current; scale 23,700 amperes per in.
5—*B* phase generator current; scale 28,200 amperes per in.
6—*A B* generator delta pressure; scale 33,000 volts per in.

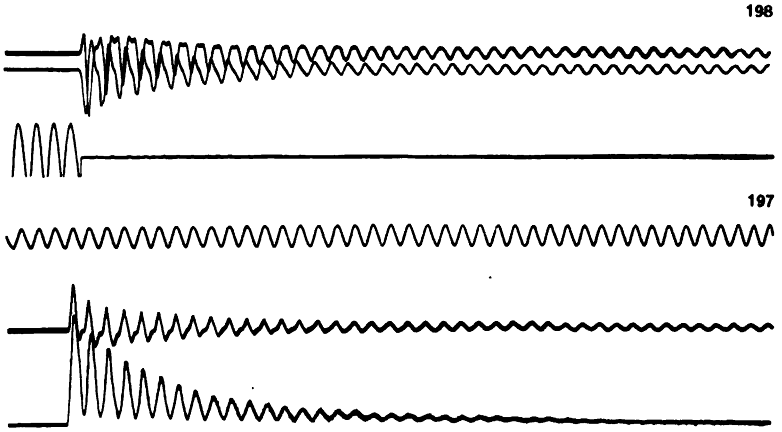
Fig. 7.—Oscillograms of a three-phase short circuit with no external reactance at 3,000 volts generator delta pressure without steam on turbine

In the tests illustrated by Figs. 7 and 9 the unit was first brought above synchronous speed. Steam was then shut off when the speed had dropped to exactly 25 cycles the short-circuiting switch was closed. The oscillograms show that the retardation of the turbine (at the pressures tested) is not affected during the first few seconds of the short circuit by the presence or absence of the steam. In other words, it is



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 42,300 amperes per in.
3—Generator field current; scale 3,300 amperes per in.
4—*A* phase generator current; scale 30,160 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; 33,000 volts per in.

FIG. 8.—Oscillograms of a three phase short circuit with no external reactance at 4,000 volts generator delta pressure with steam on turbine

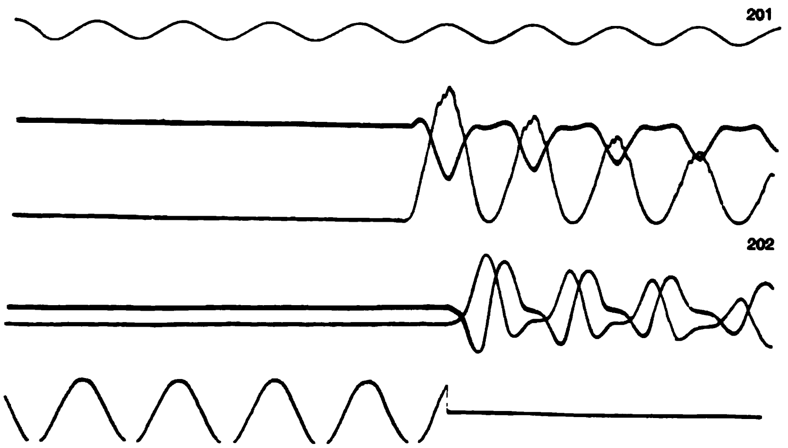


Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 42,300 amperes per in.
3—Generator field current; scale 3,300 amperes per in.
4—*A* phase generator current; scale 30,160 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; 33,000 volts per in.

FIG. 9.—Oscillograms of a three-phase short circuit with no external reactance at 4,000 volts generator delta pressure taken without steam on turbine

entirely a matter of stored energy in the moving mass. In Fig. 8 an interesting trace of field current is shown. The first rush is apparently composed of an alternating current superimposed on the direct current and both were added to the normal excitation current. Both the direct current and alternating current components disappeared simultaneously and at the end of approximately one second the normal value of excitation current was restored. The oscillograms of Fig, 10 were taken to show the wave forms of the generators and the field currents.

From the data obtained from these traces the maximum current at 3000 volts was shown to be 9800 amperes and at 4000 volts 13,000 amperes. Assuming that this proportionality to voltage holds up to normal pressure then the maximum current at normal voltage will be approximately 29,000 amperes or 27 times full load current.

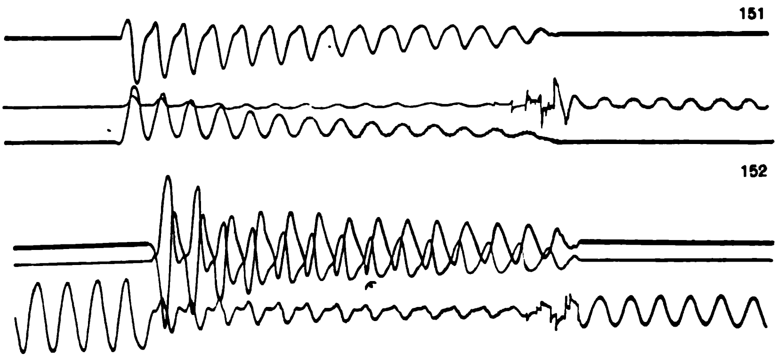


Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 42,300 amperes per in.
3—Generator field current; scale 3,300 amperes per in.
4—*A* phase generator current; scale 30,160 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; scale 33,000 volts per in.

FIG. 10.—Oscillograms of a three-phase short circuit with no external reactance at 4,000 volts generator delta pressure with steam

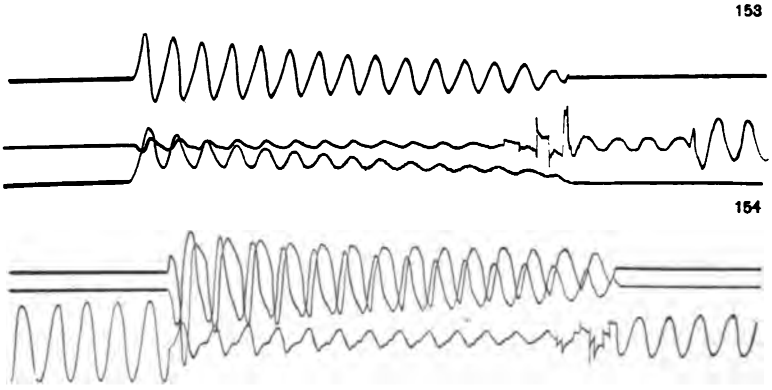
2. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITH AN EXTERNAL REACTANCE OF 4 PER CENT

It was suggested that perhaps 6 per cent is too high a value for the external reactances and for the purpose of determining the



Trace No. 1—*C* phase generator current; scale 42,300 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 16,500 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—*A* phase generator current; scale 28,680 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per.in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

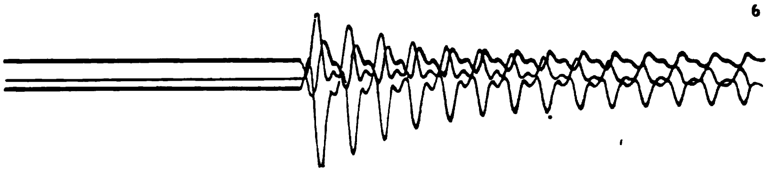
FIG. 11.—Oscillograms of a three-phase short circuit with an external reactance of 4 per cent at 7,000 volts generator delta pressure



Trace No. 1—*C* phase generator current; scale 42,300 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 16,500 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—*A* phase generator current; scale 28,680 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

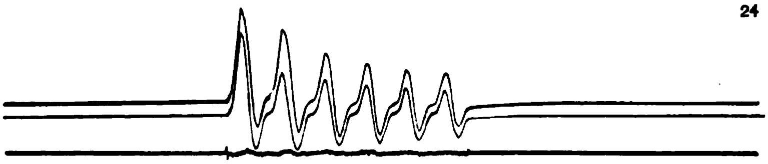
FIG. 12.—Oscillograms of a three-phase short circuit with an external reactance of 4 per cent at 8,000 volts generator delta pressure

effect of the lesser amount a series of tests was made with an external reactance of 4 per cent, using for this purpose part of the turns of the 6 per cent coils. By measurement the section used had a reactance of 0.27 ohms at 25 cycles, thus absorbing 208 volts with a flow of full load current. The data of four of these tests are given in Table II and in the curves of Figs. 11 and 12. Aside from some peculiar pressure conditions at the oil switch no points of particular importance are brought out by the oscillograms. Tests were not made at a pressure higher than 8000 volts with this reactance as the current rushes at that pressure were so high that it was thought inadvisable to subject to the generator or the switches to a grêater strain. The current values obtained indicate that at 9000 volts the maximum current would be approximately 18,000 amperes, or 16½ times full load current.



Trace No. 1—*A* phase generator current; 4,680 amperes per in.
2—*B* phase generator current; 3,600 amperes per in.
3—*C* phase generator current; scale 2,210 amperes per in.

FIG. 13.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 1,060 volts generator delta pressure



Trace No. 1—*A* phase generator current from special current transformer; scale 7,920 amperes per in.
2—*A* phase generator current from regular current transformer; scale 8,640 amperes per in.
3—Defective potential transformer fuse.

FIG. 14.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 3,000 volts generator delta pressure

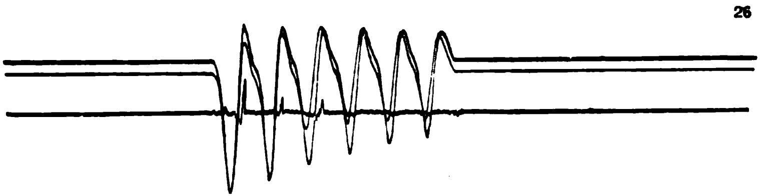
3. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITH AN EXTERNAL REACTANCE OF 6 PER CENT

There were 146 short circuits made through the 6 per cent reactances. A number of these tests, in addition to determining

TABLE II

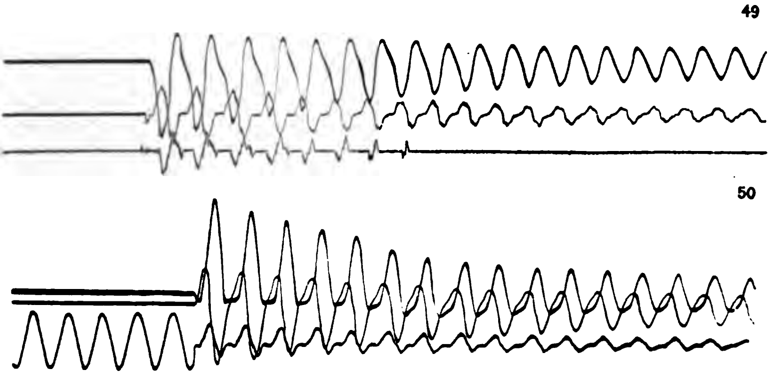
Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
59	149 150	4	H-3	3 φ	5000	+ 83%	— 6%	— 89%	7200	10200	7800	
60	151 152	4	"	"	7000	+ 58%	— 41%	— 99%	12000	14700	9900	See Fig. 11
61	153 154	4	"	"	8000	— 51%	—100%	+ 48%	13400	10400	9900	See Fig. 12
62	155 156	4	"	"	8000	+ 97%	+ 28%	— 69%	10500	14100	14850	

the characteristics and behavior of the reactances, were made for the purpose of experimentation on the oil switches and a few on potential transformer fuses. From the oscillograms obtained, the characteristics of the reactances were studied. In Table III are given the data of twenty-one of these tests and the principal



Trace No. 1—*A* phase generator current from special current transformer; scale 7,920 amperes per in.
2—*A* phase generator current from regular current transformer; scale 8,640 amperes per in.
3—Defective potential transformer fuse.

FIG. 15.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 4,000 volts generator delta pressure



Trace No. 1—*C* phase generator current; scale 17,100 amperes per in.
2—*A* phase reactance coil drop; scale 18,690 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 15,600 amperes per in.
5—*B* phase generator current; 18,900 amperes per in.
6—*A B* generator delta pressure; 54,300 volts per in.

FIG. 16.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 5,500 volts generator delta pressure

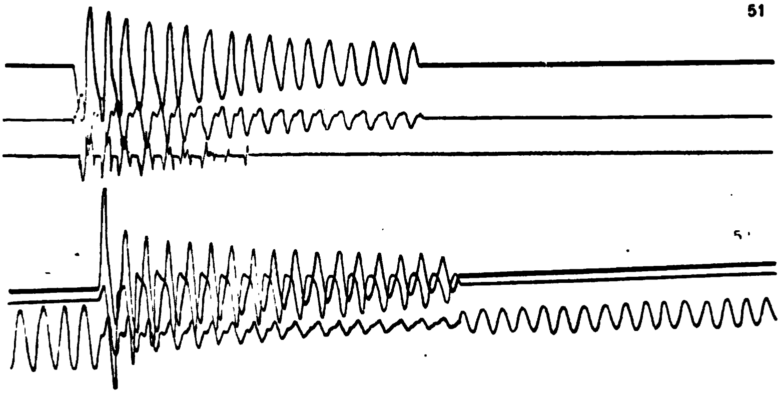
characteristics are illustrated in Fig. 13 to 20 inclusive. A very interesting fact is brought out in these oscillograms. The maximum pressure across the reactance coils is shown to occur in the latter half of the first cycle, indicating that the rate of change of the current is greater in the latter part of the first cycle than in the initial rush. Figs. 13 to 18 inclusive were

TABLE III

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
1	6	6	H-6	3 φ	1050				860	1250	960	See Fig. 13
2	7	6	"	"	1080				1200	1100	770	
3	8	6	"	"	1470				1000	1300	1150	
4	9	6	"	"	1780				1750	1700	2350	
7	21	6	"	"	2000				1950	Regular	transf.	
8	23	6	"	"	2500				3550	Regular	"	
9	24	6	"	"	3000				3600	Regular	"	See Fig. 14
11	26	6	"	"	4000				5300	Regular	"	See Fig. 15
14	45 46	6	"	"	4500	+ 56%	+ 99%	+ 43%	5700	4400	6560	
15	48	6	"	"	5000	+ 21%	— 74%	+ 95%	6800	6800		
16	49 50	6	"	"	5500	— 26%	— 97%	+ 72%	7650	5900	6600	See Fig. 16
17	51 52	6	"	"	6000	+ 50%	— 50%	100%	8300	8800	5100	See Fig. 17
18	53 54	6	"	"	6500	— 12%	— 92%	+ 80%	9100	7560	7400	
19	55 56	6	"	"	7000	+ 94%	+ 19%	— 75%	8200	11300	9700	
20	57 58	6	"	"	7500	+ 55%	— 45%	— 99%	12400	12200		
21	59 60	6	"	"	8000	— 99%	+ 53%	— 47%	7850	13400	14200	See Fig. 18
22	61 62	6	"	"	8500	+ 99%	+ 42%	— 57%	8500	14700	13500	
41	107 108	6	H-3	3 phase grounded	6000	+ 2%	+ 2%	— 86%	7200	9800	8900	
45	117 118	6	"	B phase to ground	9000	+ 47%	— 52%	+100%		15800		See Fig. 19
46	119 120	6	"	B phase to ground	9000	— 63%	+ 98%	+ 35%		8800		
47	121 122	6	"	B phase to ground	9000	— 43%	+100%	+ 57%		9300		See Fig. 20

obtained with three phase short circuits while Figs. 19 and 20 show single-phase short circuits to ground. These latter show the double-frequency field current due to single-phase short circuits and also the pressure rise on the opposite phases. The maximum value of the current obtained during the short circuits with the 6 per cent reactance and at 9000 volts was 15,800 amperes, which is 14½ times full load current.

The wave forms of the current through the reactances as well as the voltage across them were also determined, the circuit for this purpose being closed through the short circuiting bar and the field excitation being adjusted for the full load current of the turbo-generator. The traces obtained under these conditions are shown in Fig. 21. The measured voltage across each coil with this full load current is 328 volts, or a drop of 6.3 per cent.

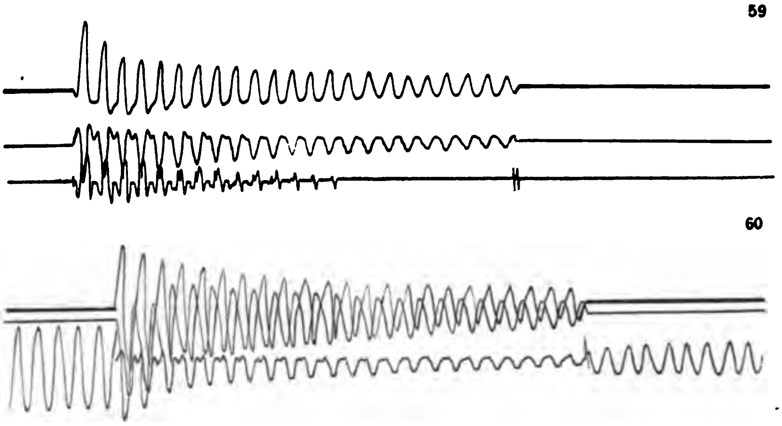


Trace No. 1—*C* phase generator current; scale 17,100 amperes per in.
2—*A* phase reactance coil drop; scale 18,690 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 15,600 amperes per in.
5—*B* phase generator current; 18,900 amperes per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 17.—Oscillograms of a three-phase short with an external reactance of 6 per cent at 6,000 volts generator delta pressure

In order to determine whether the amount of steam entering the turbine at the time of a short circuit had any effect on the results, these tests were further extended by including a series in which a load was placed on the turbo-generator and while carrying the same the short circuit was applied. Apparently the results of short circuiting a generator with load are no different from those in which the turbo-generator has no load.

Considerable discussion has been heard in regard to the probable rises in voltage due to non-simultaneous opening of the three phases of the oil switch. In eighteen of the tests made with 6 per cent reactance coils, such non-simultaneous opening is clearly indicated. The voltage rises at the switch are shown in Table III*b*, while Figs. 22 to 27, inclusive, show some of the characteristics under these conditions. Figs. 24 and 25 indicate that some of the contacts of the switch had become badly pitted which was, of course, to be expected after the very severe and continued service during the short circuits. A maximum voltage rise of over 200 per cent at some of the switch breaks is indicated in the oscillograms.



Trace No. 1—*B* phase generator current; scale 40,500 amperes per in.
2—*A* phase reactance coil drop; scale 26,100 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 23,520 amperes per in.
5—*B* phase generator current; scale 27,120 amperes per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 18.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 8,000 volts generator delta pressure

Single Phase Short Circuits with 6 *per cent Reactance.* The maximum current on a single phase to ground short circuit was 15,800 amperes, on a short circuit between two phases 12,900 amperes, and on the single phase to ground short circuit with neutral rheostat of 2.5 ohms, 2,580 amperes. Most of the single phase short circuits were made with the generator carrying substation load and pressures were taken across the load bus. Table VI shows the pressure rise on the generator and load bus. It shows that the maximum pressure rise without neutral rheo-

TABLE IIIa

Test No.	Os-cillo-grams	Per cent ex-ternal react-ance	Oil switch	Kind of short cir-cuit	Gen. delta pres-sure	Y voltages at instant before short circuit			Maximum currents			Pressures at oil switch						Remarks
												Closing switch			Opening switch			
						A ph. to ⏚	B ph. to ⏚	C ph. to ⏚	A ph.	B ph.	C ph.	A ph. to ⏚	B ph. to ⏚	C ph. to ⏚	A ph. to ⏚	B ph. to ⏚	C ph. to ⏚	
159	269 270	6	K-12	3 φ	5000	—98%	+66%	—32%	9400		9350	7700	7200	*	6600	8800	7600	*C* phase to sw. closed ½ cy before *B* phase closed.
160	271 272	6	"	"	7000	+76%	—18%	—93%	8930		11050	12600	9600	*	5000	9600	*	ditto.
163	275 276	6	"	"	8000	+22%	—73%	+95%	13600		9020	*	9600	*	7700	9600	11200	*B* phase of sw. closed10% later than *C* phase. See Fig. 22.
164	277 278	6	"	"	8000	—32%	—98%	+63%	12200		9360	4400	11200		?	9600	*	*C* phase of sw. closed before *B* phase and *A* phase.
165	285 286	6	"	"	8000	—95%	+67%	—32%	8460		12400	10500	*	*	17000	12000	?	*B* phase of sw closed about 10% after *C* phase
42	109 110	6	H-3	"	8000	—98%	+65%	—33%	10200	11900	11000	None			2700	gen.	side	*A* phase of sw. closed10% before *C* phase current.
43	111 112	6	"	"	9000	+89%	+ 6%	—83%	10200	15800	12500	None			2700	gen.	side	ditto. See Fig. 23.
44	113 114	6	"	"	9000	—35%	—98%	+62%	12400	9400	7100	None			2200	gen.	side	ditto
166	279	6	K-12	"	9000						14950		12800	*		20800	17700	ditto
167	281 282	6	"	"	9000	+81%	—11%	—92%	10340		12750	Over 22000	12800	*	13200	21100	16800	ditto. See Fig. 24.
168	283 284	6	"	"	9000	—86%	+86%	0	7800		11900	Over 22000	12000	*	7100	14400	?	ditto. See Fig. 25.
170	287 288	6	"	"	9000	—98%	+67%	—32%	11270		12750	Over 19000	12300	*	None	15200	*	*B* phase of sw. closed ½ cy. after *C* phase and *A* phase.
171	289 290	6	"	"	9000	+40%	—58%	+99%	16170		15300	17600	12800	*	8300	12000	*	*B* phase of switch closed 1 cy. after *C* phase. See Fig. 26.
172	291 292	6	H-3	"	9000	—60%	+99%	+39%	12880		14800							
173	293 294	6	"	"	9000	+70%	—27%	—97%	12220		10540							
202	337 338	6	K-12-S	"	9000	100%	+50%	—50%	7700 7950		12900		*	*		10400	None above normal	*C* phase of sw. closed 10% early. See Fig. 27.
203	339 340	6	" "	" "	9000	+95%	+23%	—72%	9400 9900		11700		*	*		15200	16800	ditto
204	341 342	6	"	"	9000	—70%	+97%	+27%	13450 13400		15800		*	*		None above normal	11200	ditto

*Pressure not above normal.

TABLE IIIA

Test No.	Oscillo-grams	Per cent ex-ternal react-ance	Oil switch	Kind of short cir-cuit	Gen. delta pres-sure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
24	69 70	6	H-6	3 φ with load	9000	— 15%	— 93%	+ 78%	14100	12200	10800	Water rheostat load of 2000 kw.
26	71 72	6	"	"	9000	+ 70%	+ 97%	+ 27%	12000	9300	14600	Water rheostat load of 6000 kw.
27	73 74	6	"	"	9000	— 72	+ 96%	+ 24%	11600	9000	14200	ditto 7440 kw.
28	75 76	6	"	"	9000	— 63%	+ 98%	+ 36%	11500	8000	12800	ditto 7880 kw.
29	77 78	6	"	"	9000	— 87%	+ 87%	0%	10000	12000	14200	ditto 7880 kw.

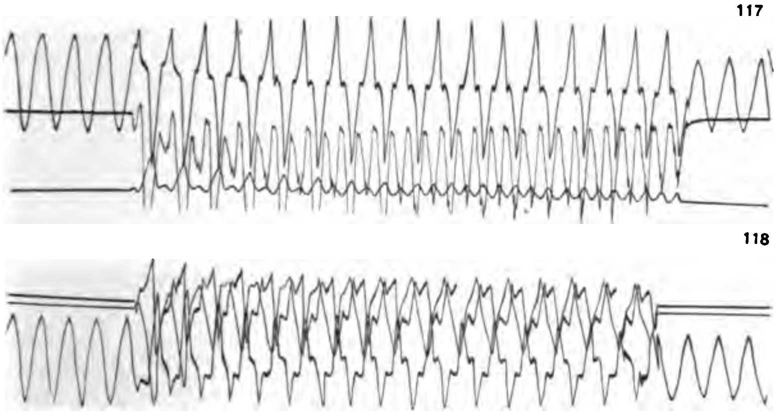
TABLE IV

Test No.	Oscillo-grams	Per cent ex-ternal react-ance	Oil switch	Kind of short cir-cuit	Gen. delta pres-sure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
63	157 158	6	H-3	3 phase	9000	+ 92%	+ 12%	— 80%	10500		12450	Taken to show retardation of turbine. See Fig. 28.
64	159 160	6	"	"	9000	— 87%	+ 87%	0%	10500		13000	ditto
65	161	6	"	"	9000						8770	Wave forms.
66	164	6	"	"	9000	0%	— 87%	+ 87%	12600	12400		ditto
67	165 166	"	"	"	9000				8200	5650	11700	ditto.

stat is 85 per cent and with neutral rheostat 125 per cent. This shows that while the neutral rheostat greatly lowers the current there is at the same time a greater pressure rise.

4. DURATION OF THE TRANSIENT PHENOMENA INCIDENT TO THE SHORT CIRCUIT UNDER CONDITIONS 1, 2 AND 3

A number of tests were made in which the oil switch was kept closed for several seconds to determine the duration of the transient phenomena. In Fig. 28 are shown the traces of various currents and pressures, and a time wave taken from the 25-cycle system is added for reference. The retardation of the turbine, as previously mentioned, is shown to be approximately ¼ of a cycle in five seconds and the current reaches a constant value in about two seconds. The difference in the rate of decrease of amplitude of the first four cycles of trace No. 1 as compared to this decrease in amplitude of subsequent cycles shows clearly the effect of the field and the armature transients.

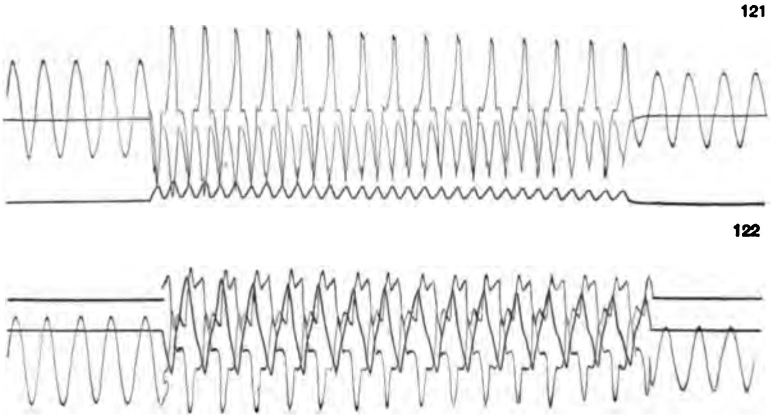


Trace No. 1—*A C* generator delta pressure; scale 52,800 volts per in.
2—Generator field pressure; scale 261 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—Drop across *B* phase reactance coil; scale 21,300 volts per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 19.—Oscillograms of a *B* to ground short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

5. THE EFFECT ON THE GENERATOR OF THESE SHORT CIRCUIT CURRENTS

A careful examination was made of the generator after each series of tests but no effect whatever could be detected. At the instant of short circuit in many cases a flash was seen within the generator. This was caused by the volatilized parts of the carbon brushes at the collector rings of the field circuit, and also by the induction of very large eddy currents in the field core. Trace No. 3 in Fig. 28 shows the variation in field current during the short circuit. This current may rise as high as 3,500 amperes due to induction from the armature circuit. The normal excitation at full load and unity power factor is 400 amperes. It is apparent from the above that the insertion of the 6 per cent coils renders the turbo-generator practically immune against failure due to the stresses incident to short circuits beyond the reactances.



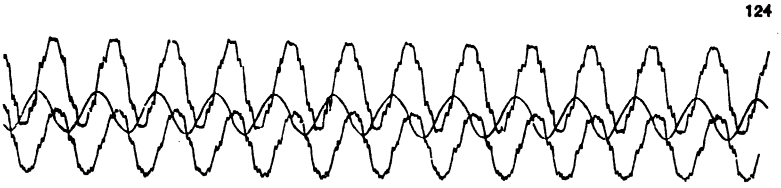
Trace No. 1—*A C* generator delta pressure; scale 54,300 volts per in.
2—Generator field pressure; scale 432 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—Drop across *B* phase reactance coil; scale 21,300 volts per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; 54,300 volts per in.

FIG. 20.—Oscillograms of a *B* to ground short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

6. THE BEHAVIOR OF THE REACTANCE COILS

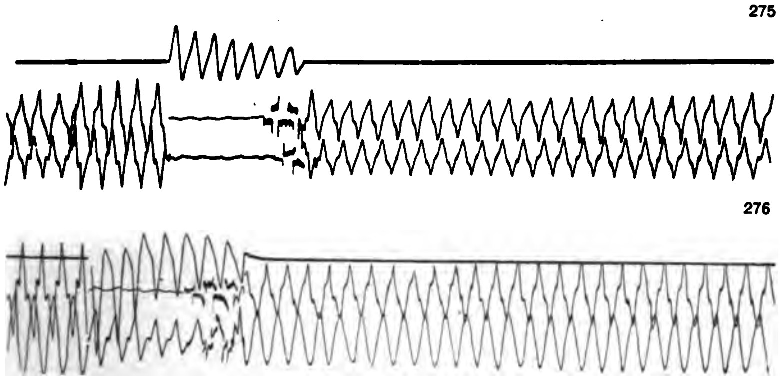
Early in the tests large iron nails were placed on the floor near the reactances to indicate the strength of the field at the time of short circuit. In test No. 23 one of these nails about two feet distant from the lower turn was drawn into the B phase coil.

A full load run was made to determine the heating of the coils and pieces of brass bar, copper and iron were placed near them. The generator was short circuited through the coils and with a current of 770 amperes a constant temperature was reached at the end of five hours. During this run the oscillogram of Fig. 21 was obtained. The tests showed that there is practically no heating in brass or copper placed near the coils. Iron bars 1 by $\frac{3}{4}$ in. in section forming a framework of an iron screen showed a temperature rise of 24 deg. cent. when placed within 12 in. of the coils.



Trace No. 1—Drop across *A* phase reactance coil, 328 volts.
2—*A* phase generator current, 768 amperes.
3—*A B* generator delta pressure, 576 volts.

Fig. 21.—Oscillograms showing wave forms of short circuit with full load current through external 6 per cent reactance on a three-phase short

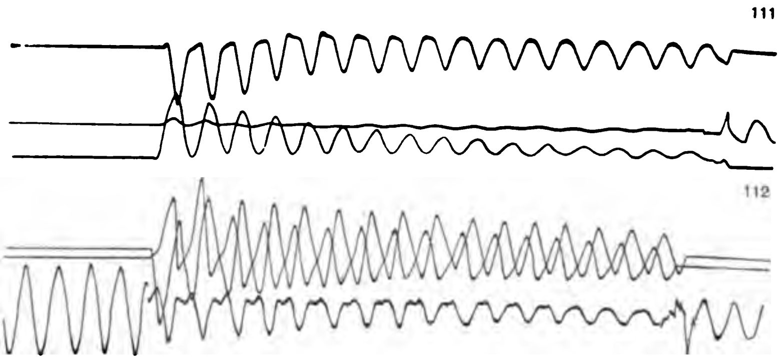


Trace No. 1—*C* phase generator current; scale 51,000 amperes per in.
2—Across *B* phase oil switch break; scale 48,000 volts per in.
3—Across *C* phase oil switch break; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—Across *A* phase oil switch break; scale 33,000 volts per in.
6—*A B* generator delta pressure; scale 54,000 volts per in.

Fig. 22.—Oscillograms showing three-phase short circuit with an external reactance of 6 per cent at 8,000 volts generator delta pressure

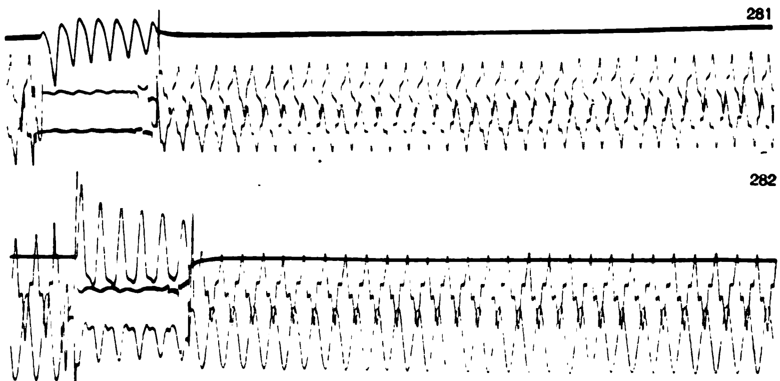
Various devices were applied to record possible movement of the coils but no such movement was detected. In the latter part of the tests the heavy braces at the top were disconnected but even with this support removed the coils showed no tendency to move.

The magnetic pull due to the field was tested by holding a



Trace No. 1—*C* phase generator current; scale 52,300 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 31,500 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—*A* phase generator current; scale 28,680 amperes per in.
5—*B* phase generator current; scale 33,900 amperes per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 23.—Oscillograms of a three-phase grounded short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

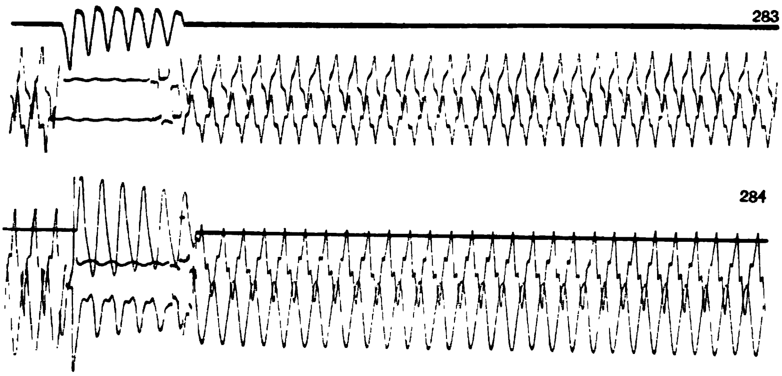


Trace No. 1—*C* phase generator current; scale 51,000 amperes per in.
2—Across *B* phase oil switch break; scale 48,000 volts per in.
3—Across *C* phase oil switch break; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—Across *A* phase oil switch break; scale 33,000 volts per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 24.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

sheet of iron screen 30 in. from one of the coils at time of short circuit. The screen was arranged to stay in position by means of a light string held by an observer, but not the slightest pull could be detected.

No pressure rises across the end turns of the coils were found. As already mentioned in the first paragraph of series No. 3, tests the maximum pressure across the coils occurred in the last half of the first cycle. The maximum voltage across a coil was found to be 7,850 volts. The maximum current during the same cycle was 11,700 amperes. The maximum drop occurred when the value of the current was about 9,000 amperes; the corresponding rate of change of the current is



Trace No. 1—*C* phase generator current; scale 51,000 amperes per in.
2—Across *B* phase oil switch break; scale 48,000 volts per in.
3—Across *C* phase oil switch break; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—Across *A* phase oil switch break; scale 33,000 volts per in.
6—*A B* generator delta pressure; scale 54,300 volts per in.

FIG. 25.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

$$\frac{d\,i}{d\,t} = \frac{e-i\,R}{L} = \frac{7850-670}{0.0027} = 2{,}660{,}000 \text{ amperes per second.}$$

7. THE EFFECT OF THE INSTALLATION OF REACTANCE COILS ON THE STABILITY OF THE SYSTEM

The stability of the system during cable breakdowns depends primarily on two things; first, steadiness of voltage, and second, steadiness of speed. The use of the reactances reduces the torque on the generators to such a point that the speed is not materially affected even by short circuits on the bus. This is

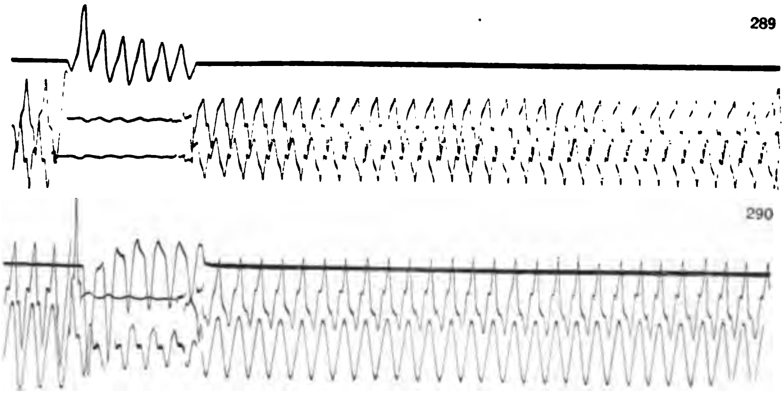
TABLE V

Test No.	Oscillo-grams	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
49	125 126	6	H-3	3 φ with load	9000	— 93%	+ 77%	— 18%	3850 11000	Substation Generator		Generator carrying 5 sub-sta. load of 1340 kw. not connected to system. See Fig. 29.
50	127 128	6	"	"	9000	+ 87%	0%	— 87%	3500 11000	Substation Generator		Gen. carrying 5 substa. load of 770 kw. not connected.
51	132	6	"	*A B* with load	9000	+ 59%	— 49%	— 99%	12900	Generator		Gen. carrying 5 substa. load of 650 kw. not connected.
52	129 130	6	"	*A* φ to gr. with load	9000	+ 58%	— 41%	— 99%	2550 14800	Substation Generator		ditto.
97	229 230	6	"	"	9000	100%	+ 50%	— 50%	8180 8000 220	Total Generator Substation		Generator carrying Market St. rotary running idle.
98	232	6	"	"	9000	— 62%	+ 98%	+ 37%	13100 360	Generator Substation		ditto. See Fig. 30.
99	233 234	6	"	"	9000	— 55%	+ 99%	+ 45%	13600 12200 360	Total Generator Substation		ditto. See Fig. 31.
100	235 236	6	"	"	9000	+ 72%	— 24%	— 96%	11900 11900 530	Total Generator Substation		Generator carrying Market St. rotary connected to D. C. system. See Fig. 32.
102	237 238	6	"	*A* φ to ground	9000	+ 98%	+ 34%	— 63%	9000			
103	239 240	6	"	*A* φ to grd. with load	9000	100%	+ 50%	— 50%	9000 8260 550	Total Generator Substation		Generator carrying split-pole rotary running idle.
104	241 242	6	"	"	9000	100%	+ 50%	— 50%	9000 8000 560	Total Generator Substation		ditto. See Fig. 33.
105	243 244	6	"	"	9000	100%	+ 50%	— 50%	9000 8740 560	Total Generator Substation		Generator carrying split-pole rotary connected to d. c. system. See Fig. 34.
106	245 246	6	"	"	9000	— 72%	+ 96%	+ 24%	14400 12700 1130	Total Generator Substation		Generator carrying 2000 kw. frequency changer. See Fig. 35.

TABLE V. (*Continued.*)

Test No.	Oscillograms	Per cent external reactance	Ol switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
107	247 248	6	*H*-3	*A* φ to grd. with load	9000	100%	+ 50%	— 50%	9360 8000 1020	Total Generator Substation		ditto.
151	259 260	6	"	"	9000	+ 90%	+ 8%	— 82%	10500 9400 470	Total Generator Substation		Generator carrying Market St. rotary connected to d.c. system.
155	261 262	6	"	"	9000	+ 98%	+ 34%	— 72%	8500 8920	Total Generator		ditto.
156	263 264	6	"	"	9000	100%	+ 50%	+ 50%	10500 10300 380	Total Generator Substation		ditto. See Fig. 36.
157	265 266	6	"	"	9000	+ 90%	+ 8%	— 63%	10700 10500 330	Total Generator Substation		ditto. See Fig. 37.
158	267 268	6	"	"	9000	+ 98%	+ 34%	— 64%	8500 8460 340	Total Generator Substation		ditto.
In the four following tests a 2½ ohm resistance was inserted to the neutral connection to ground												
197	327 328	6	"	*A* φ to grd. with load	9000	+ 65%	— 33%	— 98%	2550 2350 150	Total Generator Substation		Generator carrying standard rotary connected to d. c. system.
198	329 330	6	"	"	9000	100%	+ 50%	— 50%	2550 2350 150	Total Generator Substation		ditto. See Fig. 38.
199	331 332	6	"	"	9000	+ 92%	+ 12%	— 80%	2450 2280 130	Total Generator Substation		Generator carrying standard rotary connected to d.c. system. See Fig. 39.
200	333 334	6	"	"	9000	+ 92%	+ 12%	— 80%	2580 2280 140	Total Generator Substation		ditto.

shown clearly by the small retardation of the generator, shown in Fig. 28 previously referred to. The voltage on the bus, however, is directly dependent on the resistance of the short circuit from the bus to the fault and back, as well as on the nature of the fault, and is, therefore, practically independent of the reactances. If then the voltage drops to such a point that the synchronous apparatus connected to the system feeds back sufficient energy to actuate the overload relays on the substation units, the oil switches on these units will be opened, *i.e.*, the load will drop off. If the bus voltage does not reach a very low point or if the overload relays in the substation are provided with fixed time elements which will make them inoperative, short of, say one second, then the reactance in the generator circuit will by the phase displacement of the current cause the synchronizing component of the current to be greater, thereby making the system more stable. This is illustrated in Fig. 40 where *O A* represents the generator e.m.f., *O B* the counter e.m.f. of the substation unit, and *O C* the resultant e.m.f. causing a cross current to flow. This cross current with only a small amount of reactance in the circuit has the direction $O\,I_1$, lagging behind *O C* by angle α. This angle is increased to α', the current vector then being $O\,I_3$, when the reactance in the circuit is in-

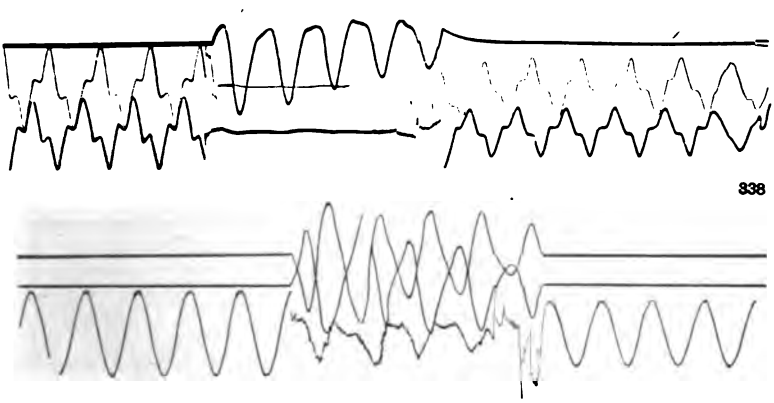


Trace No. 1—*C* phase generator current; scale 51,000 amperes per in.
2—Across *B* phase oil switch break; scale 48,000 volts per in.
3—Across *C* phase oil switch break; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—Across *A* phase oil switch break; 33,000 volts per in.
6—*A* phase to neutral generator pressure; scale 32,700 volts per in.

FIG. 26.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

creased as by the installation of generator reactances; the greater the reactance, the greater will the angle α be. The component of I in phase with the negative vector of $O\,B$, or $O\,B'$, is the energy or synchronizing current, and the increase in this value from $O\,I_2$ to $O\,I_4$ due to increase of angle α is clearly seen. All angles and the current vectors are purposely very much exaggerated for sake of clearness.

Another advantage gained by having the reactances in the armature leads lies in the fact that with lowering of the bus pressure, as by a short circuit, the generator voltage is not reduced by the same amount due to the drop in the reactances themselves. Normal pressure is thus restored more quickly.



Trace No. 1—*C* phase generator current, scale 35,100 amperes per in.
2—Across *B* phase oil switch break; scale 48,000 volts per in.
3—Across *C* phase oil switch break, scale 56,100 volts per in.
4—*A* phase generator current; regular transformer, scale 28,200 amperes per in.
5—*A* phase generator current from special current transformer, scale 29,100 amperes per in.
6—*A* phase to neutral generator pressure, scale 32,700 volts per in.

FIG. 27.—Oscillograms of a three-phase short circuit with 6 per cent reactance at 9,000 volts generator delta pressure

Various substation units of the operating system were connected to the turbo-generator under test and short circuits were then produced to note the behavior of these substation units.

It was, of course, impossible to exactly reproduce conditions of faults in the system therefore a definite comparison of the action with and without reactances cannot be made. However, from the test results the stability of the various types of substation units can be determined. The desirability of some minor changes in substation relay settings is also indicated.

TABLE VI
PRESSURE RISES AT GENERATOR AND LOAD BUS

Test No.	Os-cillo-grams	Per cent react-ance	Kind of short cir-cuit	Gen. delta pres-sure before short circuit	Generator pressure rises				Load bus pressure rises						Remarks
					Closing switch		Opening switch		Closing switch			Opening switch			
					Phase	Per cent	Phase	Per cent	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	
97	229	6	*A* φ to gr. with load	9000					None	46%	62%	None	18%	13%	Generator carrying Market St. rotary running idle.
99	233	6	"	9000					"	83%	72%	"	5%	85%	ditto
100	235	6	"	9000					"	53%	61%	"	15%	7%	Generator carrying Market St. rotary connected to d.c. system.
102	237	6	*A* φ to ground	9000					"	60%	60%	"	40%	10%	Tests made without sub-station load.
103	239	6	*A* φ to gr. with load	9000					"	57%	63%	"	25%	8%	Generator carrying split pole rotary running idle.
104	241	6	"	9000					"	57%	59%	"	30%	10%	ditto
105	243	6	"	9000					"	60%	42%	"	24%	None	Generator carrying split pole rotary connected to d.c. system.
106	245	6	"	9000					"	75%	74%	"	45%	23%	Generator carrying 2000 kw. frequency changer.
107	247	6	"	9000					"	41%	37%	"	30%	5%	ditto
109	252	6	3 phase	9000	*A B*	None	*A B*	136%							
151	259	6	*A* φ to gr. with load	9000					"	59%	56%	"	16%	?	Generator carrying Market St. rotary connected to d.c. system
155	261	6	"	9000					"	80%	94%	"	22%	53%	ditto

TABLE VI (*Continued.*)
PRESSURE RISES AT GENERATOR AND LOAD BUS

					Generator pressure rises				Load bus pressure rises						
					Closing switch		Opening switch		Closing switch			Opening switch			
Test No.	Oscillograms	Per cent reactance	Kind of short circuit	Gen. delta pressure before short circuit	Phase	Per cent	Phase	Per cent	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	Remarks
156	263	6	*A* ϕ to gr. with load	9000					None	74%	83%	None	40%	67%	generator carrying standard rotary connected to d.c. system.
157	265	6	"	"					"	70%	73%	"	36%	62%	ditto
158	267	6	"	"					"	70%	83%	"	36%	48%	ditto
160	272	6	3 phase	7000	*A B*	30%	*A B*	7%							Defective oil switch
161	274	6	"	5000	*A B*	None	*A B*	40%							ditto
164	278	6	"	8000	*A B*	93%	*A B*	None							ditto
167	282	6	"	9000	*A B*	46%	*A B*	"							ditto
168	284	6	"	9000	*A B*	43%	*A B*	25%							ditto
169	286	6	"	8000	*A B*	None	*A B*	?							ditto
170	298	6	"	9000	*A B*	Over 70%	*A B*	None							ditto
184	310	6	*A B* through bomb fuse		*A B*	20%									Pressure rise on fuse test.
172	290	6	3 ϕ	9000	*A B*	62%	*A B*	None							Defective oil switch.
In the following tests a 2½ ohm resistance was inserted in the neutral to ground															
197	327	6	*A* ϕ to gr.	9000					None	104%	20%	None	113%	20%	Generator carrying Market St. rotary connected to d.c. system.
198	329	6	"	"					"	113%	35%	"	113%	35%	ditto
199	331	6	"	"					"	120%	35%	"	120%	35%	ditto
200	333	6	"	"					"	126%	33%	"	126%	33%	ditto

TABLE VII.

Substation	Line			Unit		
	No.	Size	Length	No.	Capacity	Class
Market St..	58	4/0	17900′	3	1000 kw.	Standard converter 275 v. 214 r.p.m.
Indiana St..	87	4/0	24600′	1	1000 kw.	Split pole converter 270 v. 300 r.p.m.
Lake View..	133	250,000 cm.	35900′	4	1000 kw.	25/60 cy. frequency ch.
42nd St....	138	4/0				
	331	250,000 cm.	40500′	5	2000 kw.	Standard converter 600 v.d.c.
	332	250,000 cm.				
Grand Ave..	90	250,000 cm.	42500′	1	2000 kw.	Standard converter 600 v.d.c.

Relay settings

Substation	Unit			Substation line switch			Generating station line switch		
	Amperes			Amperes			Amperes		
	Core	2 sec.	Inst.	Core	4 sec.	Inst.	Core	2 sec.	Inst.
Market St..........	155	233	310	No relays			400	560	750
Indiana St.........	155	233	310	"			400	560	750
Lake View.........	155	233	310	"			480	670	900
		4 sec.							
42nd Ave..........	240	256	640	300	384	766	400	560	750
		2 sec.							
Grand Ave..........	310	465	620			650	480	670	900
Fault..............	(Relay controlling short circuiting switch)								2000

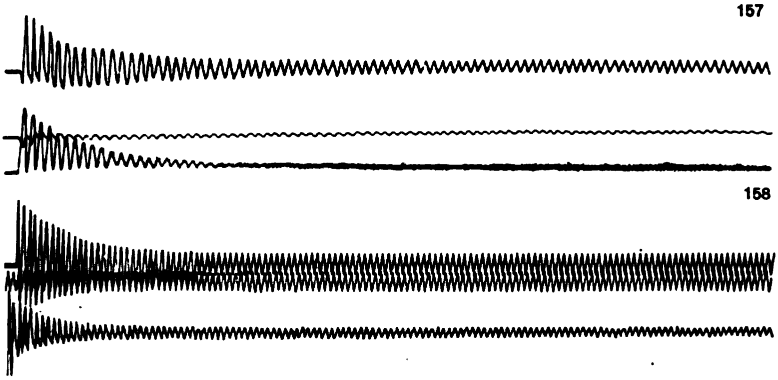
Substation	Line			Unit		
	No.	Size	Length	No.	Capacity	Class
Hyde Park..	144	4/0	32,700 ft.	2	2000 kw.	25/60 F. C. 300 r.p.m. 9000/4000 volts.
Jackson Blvd......	9 130	4/0 4/0	5,500 ft. 14,400 ft.	2	1000 kw.	Standard converter 250 volts. 214 r.p.m.

Specified relay settings

Substation	Unit amperes			Generating station Line-switch amps.		
	Core	2 sec.	Inst.	Core	2 sec.	Inst.
Hyde Park.....	310	465	620	400	560	750
Jackson Blvd...	155	233	310	400	560	750

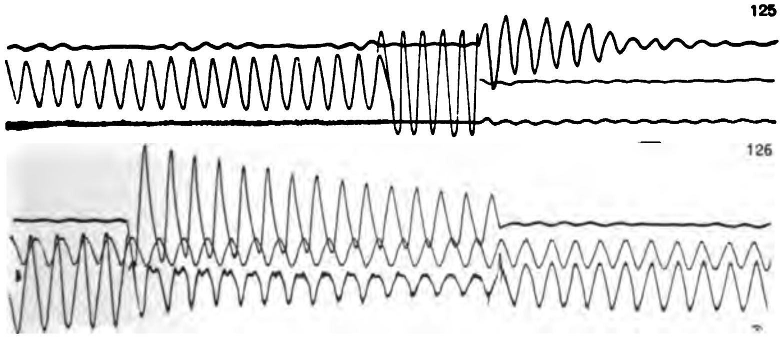
Because of the impossibility of definite and complete conclusion it was thought advisable to give the data of these tests in some detail so that any who may care to do so can study them.

Tests with a Group of Substation Units. In this series of tests five substation units in as many substations were used. The data on the lines, units and relay settings concerned are given in Table VII,



Trace No. 1—*C* phase generator current; scale 42,300 amperes per in.
2—Across *A* phase oil switch break generator side; scale 16,500 volts per in.
3—Generator field current; scale 8,400 amperes per in.
4—*A* phase generator current; scale 28,680 amperes per in.
5—Time reference wave from 25 cycle system.
6—*A B* generator delta pressure; scale 54,300 volts per in.

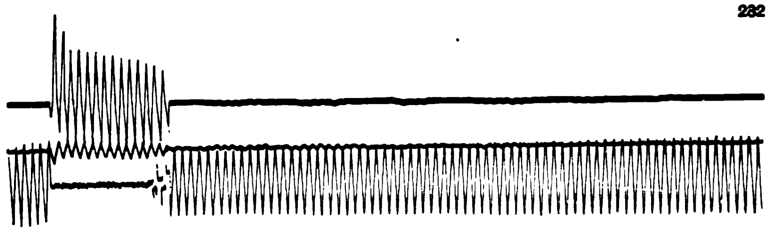
Fig. 28.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator pressure to show retardation of turbine.



Trace No. 1—*A* phase substation current; scale 16,980 amperes per in.
2—*A B* line bus pressure, scale 51,900 volts per in.
3—Defective connection.
4—*A* phase generator current; scale 28,680 amperes per in.
5—Time reference wave from 25 cycle system.
6—*A B* generator delta pressure; scale 54,300 volts per in.

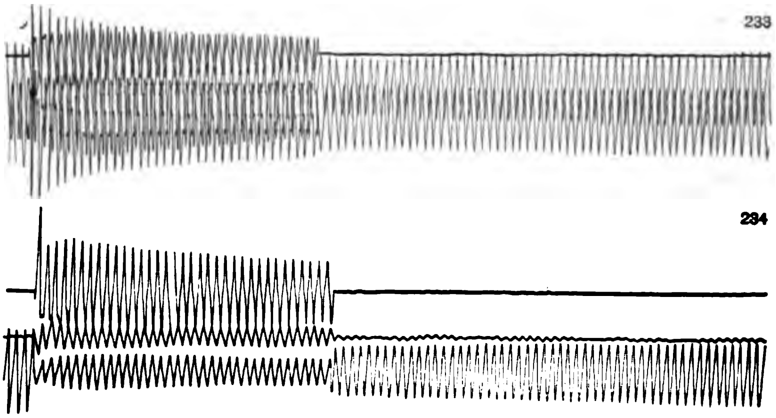
Fig. 29.—Oscillograms showing the effect of 6 per cent reactance coils on the operation of substations during a three-phase short circuit on bus

Under "relay settings" are given the current values for which the apparatus was adjusted at the last periodical check. The primary amperes are shown which are required to raise the core without time element attachments and primary amperes with time element attachments to raise the core in two seconds and instantaneously. In all substation tests the same units and relay settings were used unless otherwise mentioned.



Trace No. 1—*A* phase generator; scale 28,200 amperes per in.
2—*A* phase sub-station current, scale 6,000 amperes per in.
3—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 30.—Oscillogram showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 400:1 current transformer controlling *H*3 short circuiting switch.

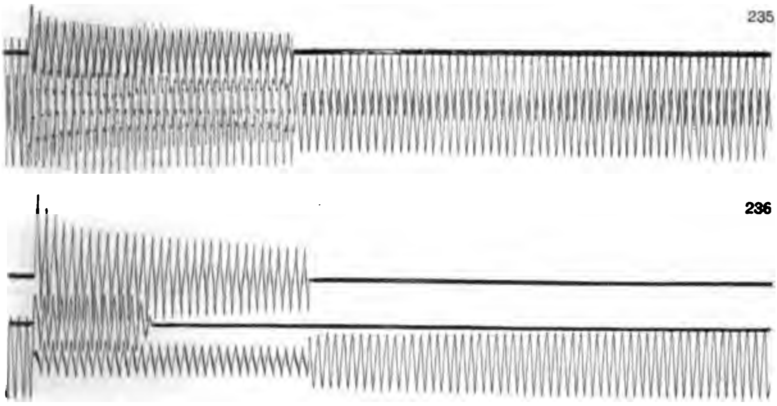


Trace No. 1—*A* phase current through short, scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 29,400 volts per in.
3—*C* phase to neutral line bus pressure; scale 33,900 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase sub-station current; scale 5,160 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 31.—Oscillogram showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Inverse time element relay on 400:1 current transformer controlling *H*3 short circuiting switch

In all four tests the five units were connected only to the 25 cycle system and there was, therefore, no possible back feed other than that due to the stored energy in the rotating members. Table V gives the oscillographic data for all the operating tests.

In Test No. 49, Fig. 29, all substation units opened the alternating current switches; Market Street in about four seconds, the others instantaneously. In Test No. 50, the Market Street unit stayed in eight seconds and would presumably have so continued but as the unit showed some sparking on the commutator it was disconnected by the operator. All other units opened the alternating current switches on reverse overload. In Test No. 51 on a single-phase short circuit between *A* and *B* phases, the Market Street unit stayed in, but the others again opened the alternating current unit switches on reverse overload. In Test No. 52 all the units stayed in except Indiana Street and even this unit hung on for about one second.



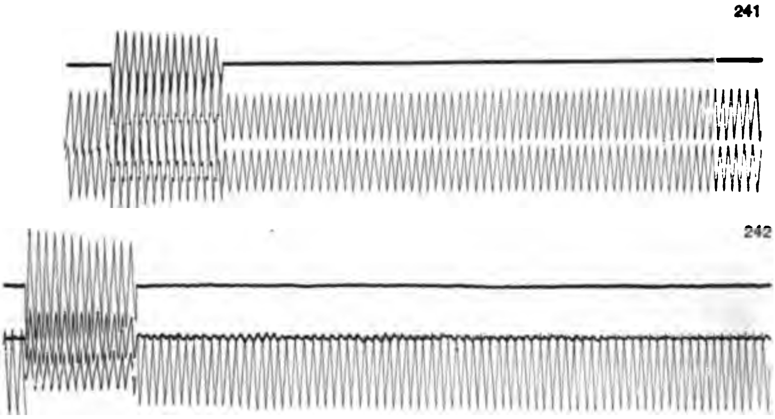
Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 29,400 volts per in.
3—*C* phase to neutral line bus pressure; scale 33,900 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 3,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

Fig. 32.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Inverse time element relay on 400:1 current transformer controlling *H*3 short circuiting switch.

In none of the tests were the line switches in the generating station opened.

Tests with Single Substation Units of Various Types. This series of tests was started with the idea of checking the operation of the individual units used in Tests No. 49 to 52 inclusive, thus eliminating any effect of cross current between substations.

Standard Converter with Induction Regulator. The first unit to be tried was No. 3 synchronous converter at the Market Street substation and for tests No. 97 and 98, Fig. 30, the H-3 short circuiting switch at Fisk Street was controlled by the same instantaneous relay used in the preceding tests connected to a 400 to 1 current transformer. In both tests the Market Street converter was running idle, connected only to the alternating current end, and in both tests the unit remained connected through to the line bus after the short. For Test No. 99, Fig. 31, and Test No. 100, Fig. 32, a new type of overload relay was substituted for the instantaneous relay as the control for the H-3 short circuit switch, and in Test No. 99 with the Market Street machine connected only to the alternating current end the unit remained in synchronism. In Test No. 100, Fig. 32, however, when the Market Street unit was connected to the direct current bus in parallel with converters No. 2 and 3 and a

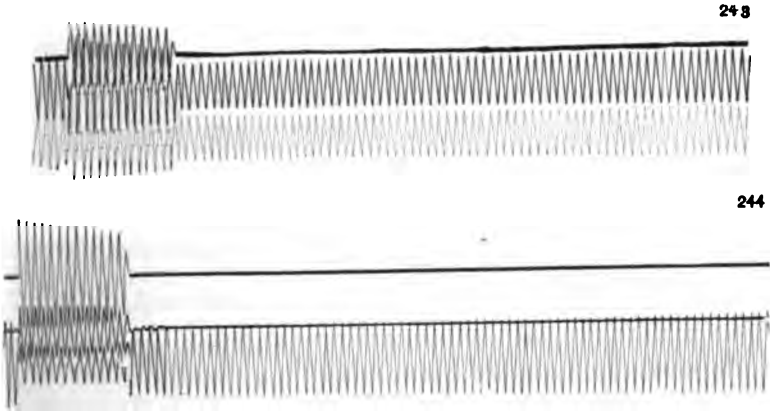


Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 4,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

Fig. 33.—Oscillograms showing effect of reactance coils on the operation of a split pole converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch

storage battery, the machine tripped out on both the alternating current and direct current sides. At the instant of short circuit in this last test the battery ammeter showed a current of 10,000 amperes and synchronous converter No. 2 ammeter about 2000 amperes.

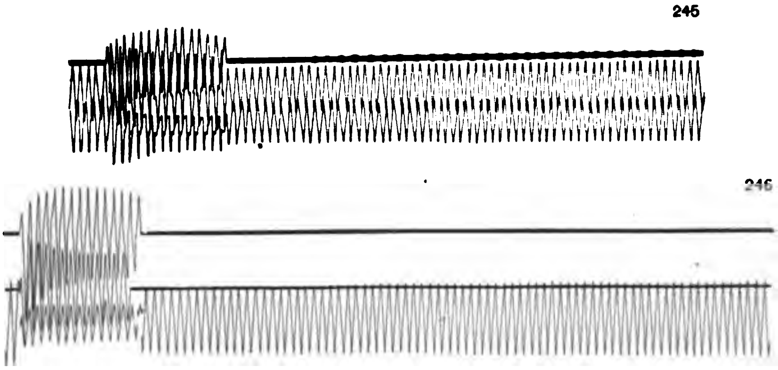
For these and all subsequent tests the short circuit was made at the end of one phase of a 200-ft. length of 250,000-cir. mil cable through an artificial fault to ground. This fault consisted of two copper plates clamped on either side of an asbestos board, through which a small hole was drilled. The two coppers represented the conductor and lead sheath of the cable while the asbestos board replaced the insulation. In this series of four tests a short length of No. 36 *I a I a* wire was connected between plates through the hole in the asbestos to start the short circuit, but in Test No. 102 and the remaining trials of substation operation the fuse wire was omitted as it was found that the artificial fault broke down gradually without previous fusing, thus more nearly duplicating actual fault conditions.



Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 53,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 3,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

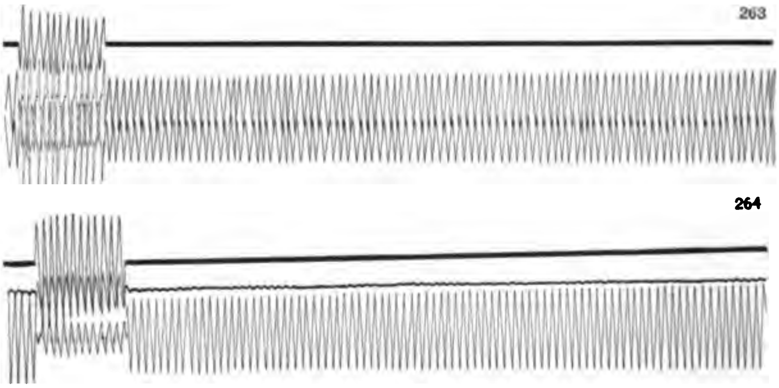
FIG. 34.—Oscillograms showing effect of reactance coils on the operation of a split pole converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch.

Test No. 151 is a repetition of test No. 100 using the in-



Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 3,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 35.—Oscillograms showing effect of reactance coils on the operation of standard frequency changer during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuiting switch

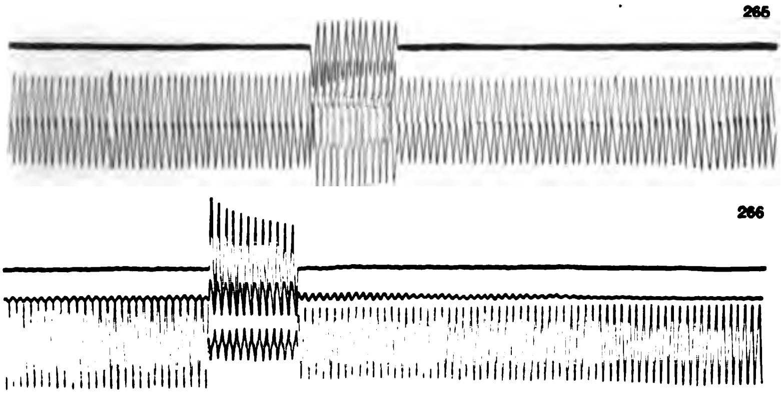


Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 3,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 36.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuit switch. Inverse time element relay controlling unit switch

stantaneous relay connected to a 60 to 1 current transformer to control the H-3 short-circuiting switch, as it was hoped that under these conditions the unit might remain connected. At the instant of short, however, the direct current circuit breakers opened on reverse current and all three phases of the unit overload relays tripped out the oil switches.

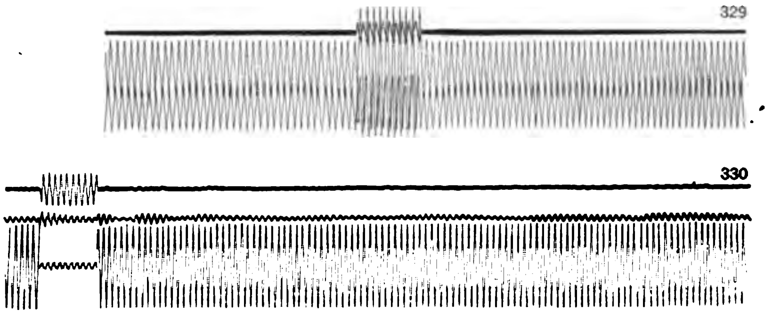
Tests No. 155, 156, 157 and 158 were made with a new type of inverse current relay previously used in certain of the former tests for control of the alternating current short-circuiting switch. This relay was installed at Market Street in place of the standard relay equipment to control the alternating current unit switch. In Tests No. 155 and 156, Fig. 36, and Test No. 158 the direct current circuit breakers opened on reverse current before the relay cones raised sufficiently to trip out the oil switch and in Test No. 157, Fig. 37, the unit remained connected to both the direct current and alternating current systems.



Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 56,100 volts per in.
4—*A* phase generator current; scale 28,200 amperes per in.
5—*A* phase substation current; scale 3,710 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 37.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during a phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuiting switch. Inverse time element relay, controlling unit switch

In all previous operating tests the neutral of generator No. 10 was connected directly to ground, the single phase short circuit current being limited therefore only by the reactance coils. As no satisfactory operating results could be obtained under these conditions it became evident that the neutral rheostat must be retained as an essential part of the system and the present group of tests were therefore made to determine the operating results when rheostat was included in the connection to short circuit. The unit at the Market Street substation which had previously been used was not available and a similar unit at the Jackson Boulevard substation was therefore used. In Tests No. 197 and 198, Fig. 38, the alternating current switch of this unit was controlled by the new type reverse current relay, while in Tests No. 199, Fig. 39, and Test No. 200 the alternating current switch control was reconnected to the standard relay equipment.



Trace No. 1—*A* phase current through short; scale 51,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 56,100 volts per in.
4—*A* phase generator current, scale 28,200 amperes per in.
5—*A* phase substation current, scale 3,000 amperes per in.
6—*A* phase to neutral line bus pressure, scale 32,700 volts per in.

FIG. 38.—Oscillograms showing the effect of reactance coils plus generator neutral rheostat on the operation of a standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch. Inverse time element relay controlling unit switch

In all four tests although the unit was connected to the direct current auxiliary bus and thence through four feeders to the direct current network, the generator neutral rheostat so limited the short circuit current that the rotary remained connected to both the alternating current and direct current systems.

Converter with Regulating Field (*Split Pole*). Tests No. 102, 103, 104 and 105 were made with the generator carrying the Indiana St. 1000-kw. split pole converter. In all tests the short-circuiting switch was controlled by the instantaneous relay, as the split pole converter opened on the alternating current end. In Tests No. 103 and 104, Fig. 33, when running disconnected from the direct current end, and in Test No. 105, Fig. 34, when running on the direct current auxiliary bus connected to the direct current network through three feeders. It was, therefore, not necessary to make further tests with the time element control of the short-circuit switch.

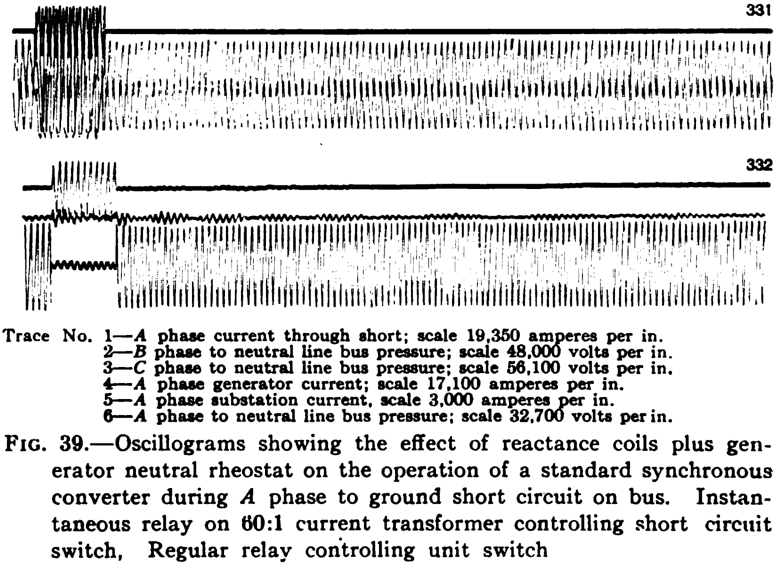
Frequency Changer Unit (9000 *Volt*, 25 *Cycle Synchronous Motor*). Tests No. 106, Fig. 35, and Test No. 107 were made with a standard 2,000-kw. frequency changer at the Hyde Park substation instead of a 1,000-kw. frequency changer at the Lake View substation used in Tests No. 49 to 52 inclusive. In both trials made with the unit connected to the 25-cycle end only, the unit oil switch opened and in Test No. 106 the line switch at Fisk Street also opened, the noise of this latter short circuit giving the observers the impression that it was very severe. No trials were made with the time limit relay as the unit was too unstable for satisfactory operation even with instantaneous control of the short circuiting switch.

The full data on lines, units and relay settings concerned in these operating tests are given in the Table VII, page 1178.

General Discussion of Results

The insertion of 6 per cent reactance reduces the instantaneous current on a three phase short from 27 to 14.5 times the full load current. In addition to this, account must be taken of the phase relation of this current to the voltage producing it. With the reactances in, the total resistance of the circuit was 0.033 ohms. The maximum Y pressure is 7350 volts, the impedance of the entire circuit including the effect of armature reaction, self-induction of the winding and the external reactance is $\frac{7350 \text{ volts}}{15{,}800 \text{ amperes}}$ or 0.46 ohms, therefore, the power factor at this current is apparently $\frac{0.033}{0.46}$ or 7.2 per cent. Without external reactance the resistance of the total circuit is that of the armature winding alone, or 0.025 ohms. The impedance of the armature circuit from test equals $\frac{7350 \text{ volts}}{29{,}000 \text{ amperes}}$ or 0.25 ohms per phase therefore, the power factor of the current is apparently 10 per cent. As this armature circuit is embedded in iron there must be a very appreciable hysteresis loss which is true energy. The actual power factors are therefore probably several times the values given above. The decrease in power factor due to the reactances is in greater ratio than 10 to 7.2 (from above values) as the hysteresis component of the energy is also smaller with the lesser current resulting from the insertion of reactances. The energy due to a sudden short circuit is reduced in proportion to the power component of the current, therefore, the shock on the generator will be a great deal less with reactances than without reactances. The strains on the coils, however, are directly proportional to the square of the current and therefore would be over three times as great without external reactance as with such reactance.

If the two machines are thrown together 180 deg. out of phase the e.m.f. in the entire circuit is doubled as are also the resistances and reactances. Therefore the armature current is the same as if the machines were short circuited at their terminals, that is, a possible maximum of 15,800 amperes. If the machines are thrown into a circuit partly out of step the maximum current is equal to the short circuit current multiplied by the sine of half the angle of phase displacement. At Fisk Street five machines are run in parallel during the peak. Where four machines are feeding a bus and the fifth is thrown in 180 deg. out of step the total e.m.f. is doubled while the resistances and reactances are increased only 1.25 per cent. This means that there



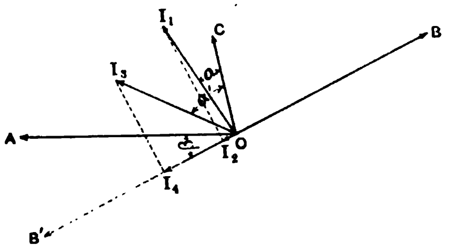
Trace No. 1—*A* phase current through short; scale 19,350 amperes per in.
2—*B* phase to neutral line bus pressure; scale 48,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 56,100 volts per in.
4—*A* phase generator current; scale 17,100 amperes per in.
5—*A* phase substation current, scale 3,000 amperes per in.
6—*A* phase to neutral line bus pressure; scale 32,700 volts per in.

FIG. 39.—Oscillograms showing the effect of reactance coils plus generator neutral rheostat on the operation of a standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuit switch, Regular relay controlling unit switch

would flow an instantaneous current 60 per cent greater than the short circuit current of the machines. With 6 per cent reactance in series with each generator this would amount to 25,300 amperes. Without external reactance this would amount to 46,000 amperes assuming no saturation.

When external reactances are used, the drop across the reactance of the incoming machine might be as high as 13,000 volts. It is, therefore, doubtful if the reactance as designed would protect the generator entirely in case of very bad synchronizing. The 25,300 amperes is 60 per cent more current than on any short circuit and some of the short circuits while they did not harm the turbine, resulted in a fairly severe shock.

If five turbo-generators are running in parallel and an internal short circuit occurs on one of them it can be assumed its voltage drops to zero. The other four machines will then feed into it. The reactances in the generator leads and the other four sets of reactances will limit the current from the busses. Figuring the generator reactances as 4 per cent and the external reactance as 6 per cent the amount of reactance to limit the current will be 6 per cent + ¼ of 10 per cent or 8½ per cent. The pressure across the terminals of the defective machine would be 9000 volts. Therefore the current that would flow would be 100/85 of 15,800 or about 18,600 amperes.



$O\ A$—Generator e.m.f.
$O\ B$—Counter e.m.f. of substation unit.
$O\ B'$—Negative vector of $O\ B$
$O\ C$—Resultant e.m.f. (of $O\ A$ and $O\ B$) causing cross current to flow
$O\ I_1$—Cross current with small amount of reactance
$O\ I_2$—Active or synchronizing component of $O\ I$
$O\ I_3$—Cross current with larger amount of reactance in the circuit
$O\ I_4$—Active or synchronizing component of $O\ I$

FIG. 40

In order to find the maximum instantaneous kilowatts of turbo-generator No. 10 during short circuit, curves of the armature and field current were taken from representative oscillograms No. 317

and No. 318 and drawn to scale. These are shown in Figs. 41 to 44 inclusive. The curves show the armature and field currents for the first cycle during a three phase short circuit with 6 per cent external reactance at 9000 volts generator delta pressure.

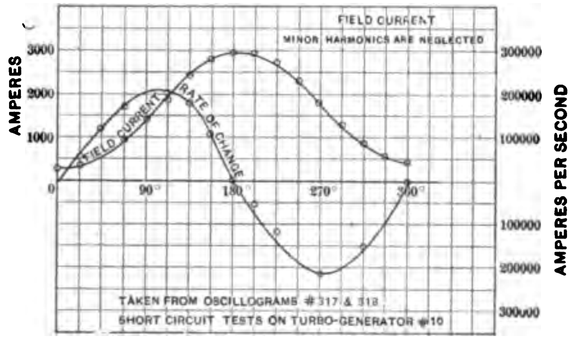


FIG. 41.—Curves showing wave forms and rate of change during a three-phase short circuit with 6 per cent reactance at 9,000 volts

Neglecting other losses, the addition of the $I^2 R$ values gives the total power generated.

The resistance of the entire circuit per phase included armature, reactance and oil switches, as measured was 0.033 ohms.

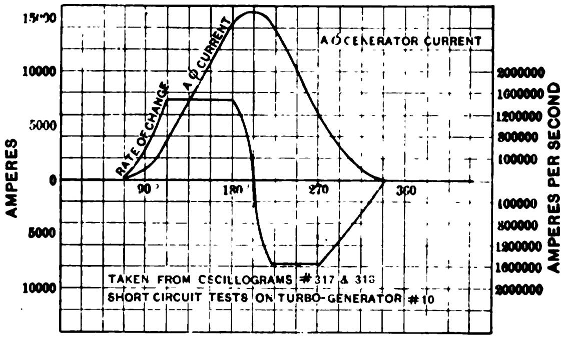


FIG. 42.—Curves showing wave forms and rate of change duringa three-phase short circuit with 6 per cent reactance at 9,000 volts

Oscillograms show, however, considerable drop across the oil switch used for short circuiting. This drop from a number of oscillograms corresponded to a resistance of 0.1 to 0.18 ohms. This value is not very accurate on account of the small deflection on the oscillograms measured. The oscillograms also show that this drop is not always directly in phase with the current. The resistance of the generator field circuit was 0.4 ohms, neglecting exciter resistance.

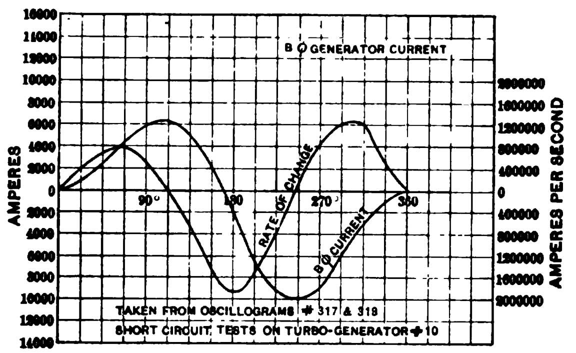


FIG. 43.—Curves showing wave forms and rate of change during three-phase delta short circuit with 6 per cent reaction of 9,000 volts

Assuming no extra resistance in the switch, the maximum instantaneous kilowatts as shown in the illustrations occurred at 190 deg. At this time the values are *A* ϕ, 8000 kw., *B* ϕ, 1320 kw. *C* ϕ, 2,670 kw., field (induced only) 2,720 kw., total 14,700 kw. The full load kw. is constant for a balanced load and is 12,000 kw. Therefore, the maximum instantaneous torque is 1.2 times the full load torque. If 0.1 ohm is added for the switch, the maximum instantaneous torque becomes 4.8

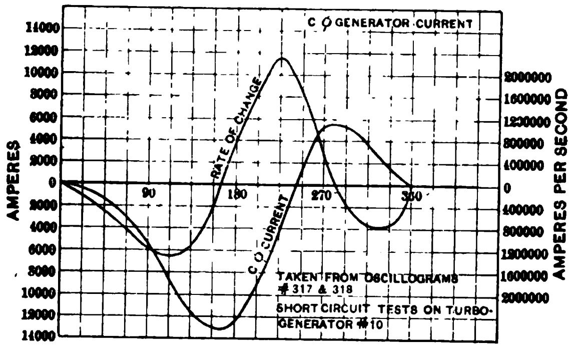


FIG. 44.—Curves showing wave form and rate of change during a three-phase delta short circuit with 6 per cent reactance at 9,000 volts

times the full load torque. This neglects the power supplied to the field by the exciter and the power losses due to the stray magnetic flux of the armature reaction.

The mean kilowatts during the first cycle as shown in the illustrations are as follows: *A* ϕ 1,940 kw., *B* ϕ 1,000 kw., *C* ϕ 1,440 kw. Field (induced only) 1,300 kw., total 5,680 kw.

The average kilowatt rating of the generator is 12,000 kw. Therefore, the average torque for the first cycle is 0.47 times full load torque. If 0.1 ohm is added for the switch, the average torque for the first cycle is 1.9 times full load torque.

A curve showing the maximum instantaneous short circuit current with various values of external reactances is given in Fig. 45.

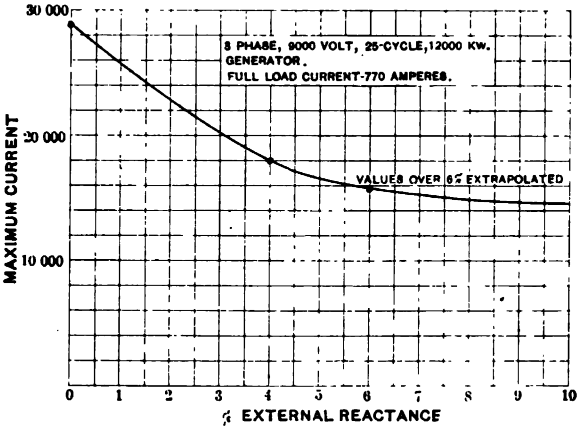


FIG. 45.—Maximum amperes on short circuit with different external reactances. Turbo-generator No. 10 at Fisk Street Station.

SUMMARY AND CONCLUSIONS

All of the preceding data and discussion can be briefly summarized in a few general conclusions, as follows:

Experience with many large capacity, high speed generators, indicates the need for reducing the possible current which may flow into a fault.

The tests indicate that the instantaneous short circuit current of these generators is actually not as high as has been thought but that this current, due to its comparatively high power factor, produces severe stresses on the generator and seriously strains the oil switches.

In order to reduce the severity of these strains and their wide spread effect in system disturbances, it is desirable to have a higher value of reactance in the generator circuit than many of these large capacity generators have been designed for. In the case of the 12,000-kw., 9000-volt, 750-rev. per min., 25-cycle units it appears that an external reactance of approximately 6 per cent is desirable. A lesser value than this does not reduce the current sufficiently and a greater value results in a very small increment of decrease. This is also true for the 6 per cent reactance with regard to the torque on the generator resulting from the short circuit.

Such reactances will limit the current to a value where it can be safely interrupted by properly designed oil switches and will keep the torque on the generator down to so low a value that even when feeding into a short circuit at the busbars there is no appreciable lessening in speed nor is the unit subjected to severe strains.

The use of the neutral rheostats at Fisk Street should be continued even after the reactances are installed as the combination of these two pieces of apparatus tends materially toward lessening the spread and severity of short circuits, which, in most cases at least, start as single-phase short circuits.

Operating experience, covering a period of about two years with reactances in connection with 5000-kw., 9000/20,000-volt transformers, shows these coils to be apparently very effective in the desired direction.

The use of reactances tends to make the operation of the system as a whole more stable and, therefore, increases the reliability of the service. The use of such coils, therefore, is apparently the solution of one of the most serious problems and as a result in a large measure of the extensive tests described above, we may now rest assured that the heavy investments already made and still to be made in power stations of great magnitude are secure, and that the safe-guarding of these very large capacity units, which have aided so materially in reducing the cost of the product, is a definite accomplishment.

Acknowledgment is due to the various engineers engaged on the tests, to Mr. E. B. Merriam and staff from the General Electric Company, Messrs. W. A. Durgin, N. J. Conrad, R. H. Whitehead and others from the Testing Department of the Commonwealth Edison Company and especially to Messrs. Durgin and Whitehead for assistance in working out the very complete set of results which permitted a proper correlation of the data and its presentation in this paper.

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SOME RECENT TESTS OF OIL CIRCUIT BREAKERS

BY E. B. MERRIAM

INTRODUCTION

Whenever an electrical circuit carrying considerable energy is opened in oil, gases are generated. These expand and rise, and tend to force the oil out of the containing vessel. They also form with air explosive mixtures, and either explode, or burn for a considerable length of time when ignited. It is important, therefore, that oil circuit breakers be provided with strong oil containing vessels in order that they may withstand the high initial stresses which are often present under certain conditions and also that suitable provision be made for retaining the oil.

In order to check tests made on moderate capacity circuits and to study the operation of oil circuit breakers and current limiting reactances on circuits of large capacity, under various conditions, arrangements were made through the courtesy of the management of the Commonwealth Edison Company of Chicago, Ill., to use one of its generating units as a source of power for tests.

APPARATUS

These tests were made at the Fisk Street Station (Fig. 1) during the early part of the year, using a three phase, 12,000-kw., 9000-volt, 25-cycle, turbo-alternator.

The following apparatus was made up at the factory and shipped for test:

3 current-limiting reactances, Fig. 2 (no iron core).

1 standard triple-pole type F form H-3 oil circuit breaker (8 in. diameter oil vessel).

2 special triple-pole type F form H-3 oil circuit breakers.

1 standard triple-pole type F form H-6 oil circuit breaker (10 in. diameter oil vessel).
3 standard single-pole type F form K-2 oil circuit breakers.

FIG. 1. —Interior of Fisk street station, Commonwealth Edison Company

1 special triple-pole type F form K-12 oil circuit breaker.
3 special single-pole type F form K-12 oil circuit breakers.

The connections are given in Fig. 3.

For the purposes of observation and measurement, use was made of two three-element electromagnetic oscillographs, one three-element arc length recorder, a special gas engine indicator, special spark gaps, movement recording devices, etc.

METHOD OF TESTS

Practically all of the tests were either three phase or single phase short circuits, some to ground and some between phases. The short circuits were made by closing the triple pole type F form K-12 oil circuit breaker shown in Fig. 4.

FIG. 2.—One unit of generator current-limiting reactances

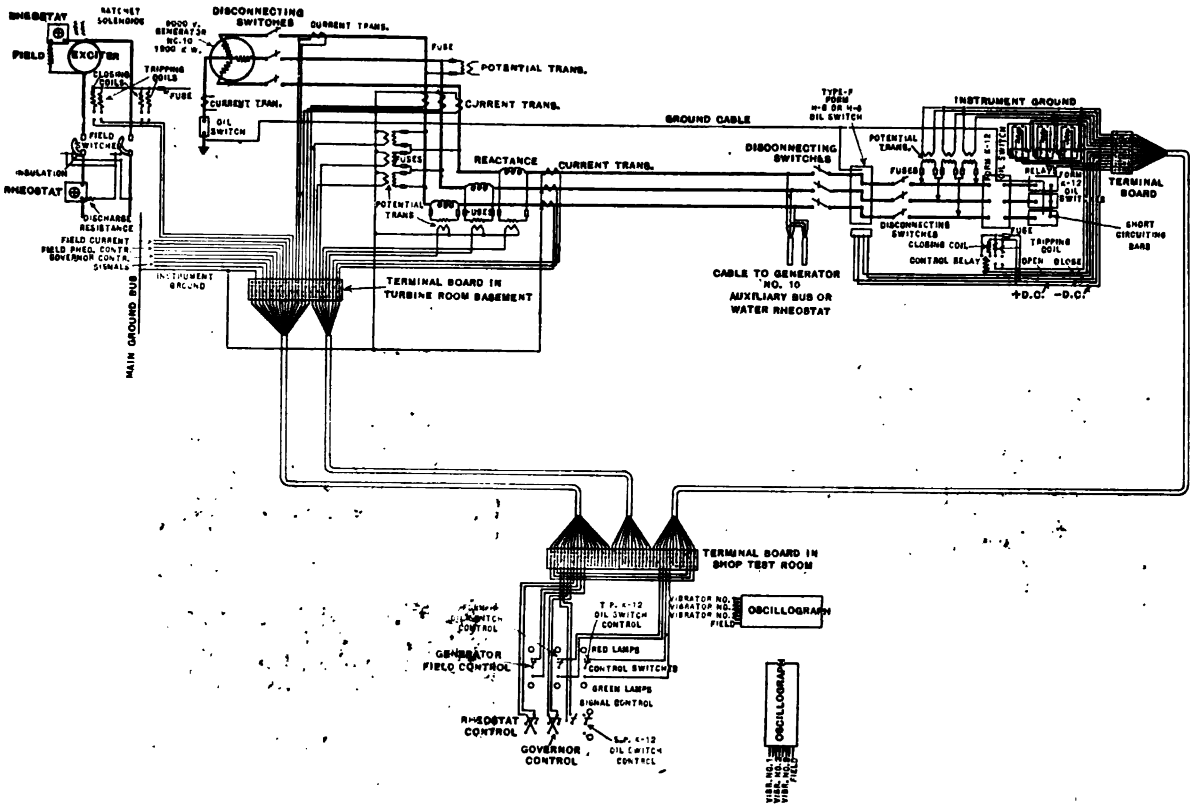

FIG. 3.—Wiring diagram of test circuits

The switch under test then automatically opened the circuit, being tripped by instantaneous relays operated from current transformers.

Fig. 4.—Solenoid-operated oil circuit breaker used for throwing on shor circuits

Observations

During all the tests, an endeavor was made to note everything of value which occurred and a series of readings were taken as follows:

Fig. 5.—Flashlight of generator current-limiting reactances during test No. 27

1. Oscillograms were made showing the relation between the currents and voltages of the various circuits, such as alternator armature current, alternator armature voltage, alternator field current,

alternator field voltage, voltage drop across reactances and voltage drop across oil circuit breakers.

2. Pieces of iron of small weight and size, placed at known locations were permitted to be displaced by the stray fields of the reactances in order to indicate the external efforts of these fields.
3. Thin strips of paper were attached to the reactance coils (Fig. 5) in such a manner as to make it impossible for the coils to move without tearing the strips.
4. Spark gaps were placed across the end turns of the reactances in order to detect any voltage rise.
5. Indicator cards were taken to show the stresses developed in the oil vessels of the various circuit breakers during test.
6. The length of arc in the oil circuit breakers under test was measured during test.

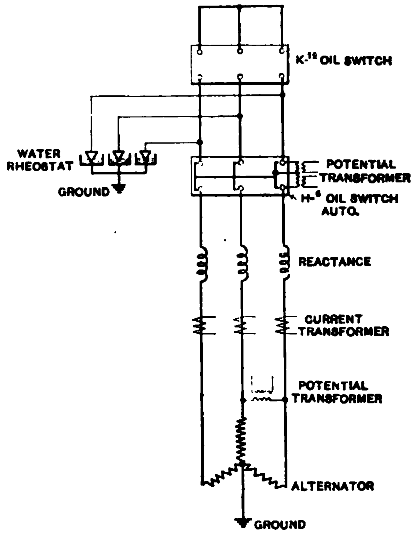

Fig. 6.—Diagram of connections for test No. 27

7. Speed records were taken of the various oil circuit breakers during test in order to permit analyzing the various arc length and pressure records.

Tests

Approximately 150 short-circuit tests were made during this series and the ones given below have been selected as representative.

Test No. 27. For this test, connections were made as in Fig. 6, the oscillograph vibrators being connected to the secondaries of the current and voltage transformers shown. It will be noted that a water rheostat was connected between the H-6 oil circuit breaker (Fig. 7) and the K-12 oil circuit breaker (Fig. 3). It should also be noted that the reactance in each phase gave a drop of approximately 312 volts at rated load current of the alternator, this being known as a 6 per cent reactance. An initial load of about 7500 kw. was placed on the alternator by the water rheostat and the K-12 oil circuit breaker was then closed, super-imposing a short circuit on the testing system. Oscillograms Figs. 8 and 9 show the events which then occurred and Fig. 10 shows the length of the arc and the stress which was developed near the wall of " A " phase generator oil vessel.

Fig. 7.—Type F form H-6 oil circuit breaker during test No. 27

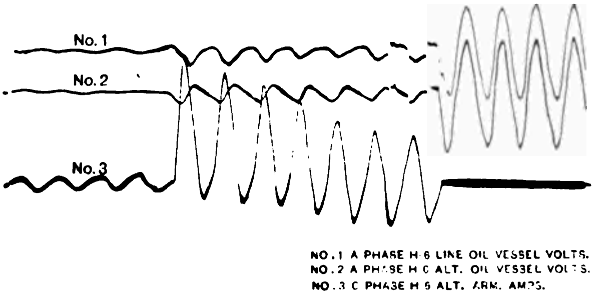

Fig. 8.—Oscillogram A test No. 27

During this test, some smoke came out of the oil vessels and a few drops of oil were drawn up by the switch rods along the inside of the bushings of the oil vessels and splashed out. The reactance windings were not displaced nor did the recording apparatus detect the slightest movement of the coils, although this was one of the worst short circuits recorded.

Test No. 32. Connections for this test are shown in Fig. 11. There was no initial load connected to the alternator and the circuit breaker under test was an H-3 having 8 in. diameter oil vessels fitted with the baffles shown in Fig. 12. As before, the oscillograph vibrators were connected to the secondaries of the voltage and current transformers and the shunt shown in the wiring. The short circuit was thrown on by the K-12 oil circuit breaker. The resulting oscillograms are given in Figs. 13 and 14 and the stress in the generator oil vessel of " A " phase, velocity of the oil circuit breaker contacts, and the arc length record are given in Fig. 15. Some oil and smoke came out of the H-3 oil vessels during this test. Besides this, the generator oil vessel in " B " phase was distended sufficiently by the pressure developed within it to permit its top to be forced out but without in any way injuring the threads. On examination, it was found that the expansion bolt in this top had not been tightened. The top was then replaced, the expansion bolt tightened and no trouble of this nature was recorded in any of the succeeding tests.

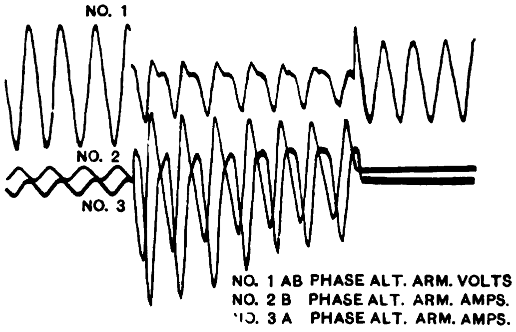

FIG. 9.—Oscillogram B test No. 27

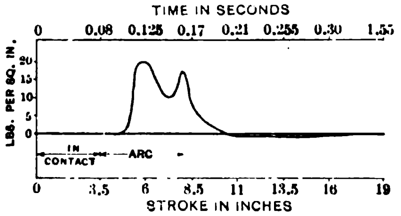

FIG. 10.—Arc length and pressure records test No. 27

Test No. 61. Connections were made as shown in Fig. 16. The reactance was changed so as to have only 4 per cent in series in each phase of the generator. The H-3 oil circuit breaker was fitted with oil diverters shown in Fig. 17 and as before, the oscillograph vibrators were connected to the secondaries of the current and voltage transformers and the shunt in the generator field. The oscillograms obtained are shown in Figs. 18 and 19 and the arc length, stress records, etc., are shown in Fig. 20, the speed curve being developed in Fig. 21. During this test, some oil and smoke came out of the oil vessels of the H-3 switch. Some burning gases came out of the " cuckoo door" of generator oil vessel in " C " phase and it was also noted that the door of this cell opened a little bit.

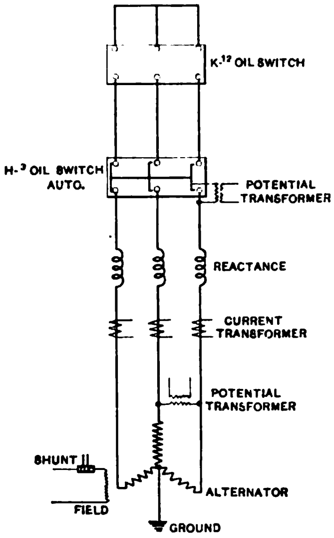

Fig. 11.—Diagram of connections test No. 32

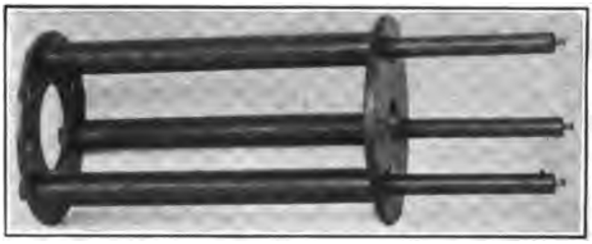

Fig. 12.—Baffle of H-3 oil circuit breaker used in test No. 32

Test No. 171. Connections for this test were made as in Fig. 23 and 6 per cent reactance was replaced in each of the phases. The triple pole type F form K-12 oil circuit breaker was made automatic and opened the short circuit which was thrown on the system by the three (3) single pole type F form K-12 oil circuit breakers. The resulting oscillograms are shown in Figs. 24 and 25 and the pressure diagrams and arc lengths in Fig. 25. During this test, some smoke and oil came out of the oil vessels but both were directed downward by the external diverters with which this circuit breaker was equipped. These proved very effective and did not permit the oil and gases to be thrown outward.

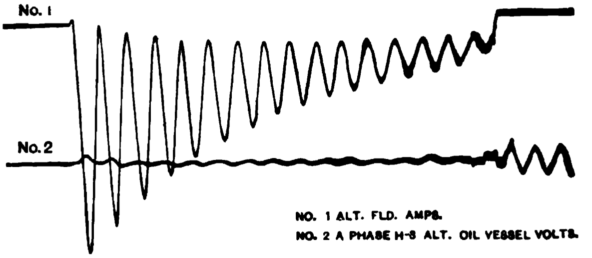

FIG. 13.—Oscillogram A test No. 32

Test No. 173. Connections for this test were similar to those shown in Fig. 23. The H-3 oil circuit breaker was made automatic and one phase fitted with an oil diverter. Short circuit was thrown on by the triple pole K-12 oil circuit breaker and the resulting oscillograms are given in Fig. 27, the arc length and stress diagrams being shown in Fig. 28. The action of the H-3 oil circuit breaker during this test is shown in Fig. 29. It is seen therefrom that some smoke and oil came out of " C " phase oil vessels and some smoke came from " B " phase oil vessels, while " A " phase oil vessels showed no external disturbance. For this test, the " A " phase oil vessels were fitted with oil diverter shown in Fig. 17, " B " phase oil vessels were fitted with a special oil diverter. " C " phase oil vessels were fitted with oil diverter shown in Fig. 12, thus giving a comparison of the action of these three schemes.

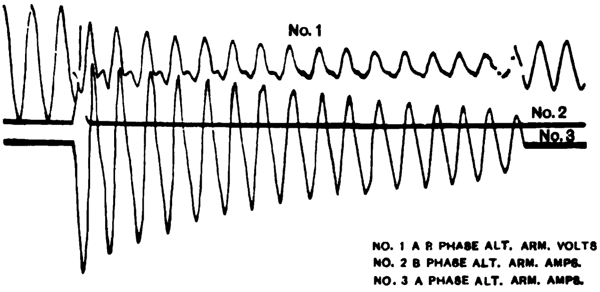

FIG. 14.—Oscillogram B test No. 32

EFFECT OF SHORT CIRCUIT ON GENERATOR

In tests of this nature, it has always been noted that the field current of the alternator rises when the armature is short circuited. Values as high as ten times field current at rated no load voltage of the alternator were observed during these tests and the form of these field currents is shown in Figs. 13 and 18. This phenomenon is dependent upon the inter-action between the field and armature coils, and the maximum value which the field current attains is dependent upon the co-axial relation of the two circuits and their electrical constants. It was also noted during this series of tests that spits of fire came out of the

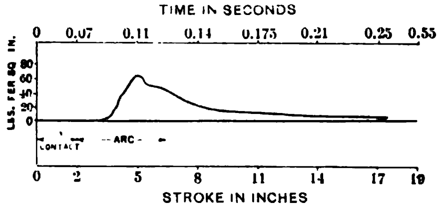

FIG. 15.—Arc length and pressure records test No. 32

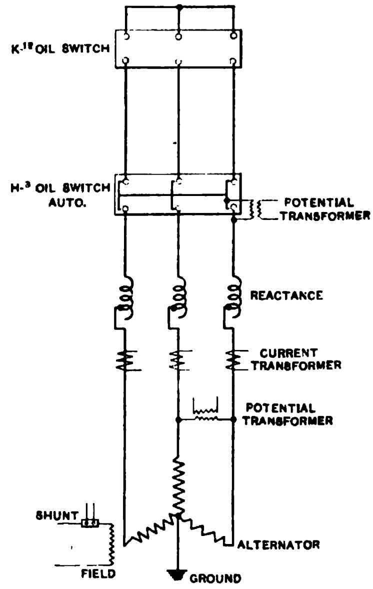

FIG. 16.—Diagram of connections for test No. 61

alternator field. This has often been noticed in connection with high voltage transformers suddenly thrown on a live circuit and is doubtless due to the very high voltage induced in the alternator field windings when a short circuit current is established in the alternator armature. Our records show that this voltage can be as high as seven times normal, although it may have been considerably higher, since we only made a few measurements.

FIG. 17.—Oil diverter of H-3 oil circuit breaker used in test No. 61

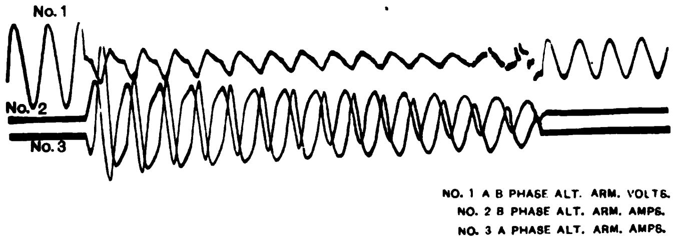

FIG. 18.—Oscillogram A test No. 61

In some of the single phase tests and also in some of the tests where the short circuit was thrown on by three (3) single pole circuit breakers, it was noticed that the voltage of the phase not short circuited rose to a very high value, some times as high

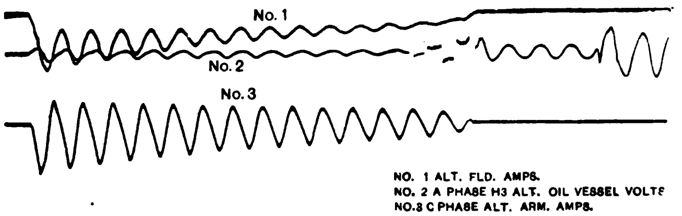

FIG. 19.—Oscillogram B test No. 61

as two and a half times normal. This was probably due to the very large current induced in the field, which, acting on the unloaded phase, produced a voltage rise.

The end turns of the alternator did not move during any of these tests, a rigid inspection being made at frequent intervals to detect any such movement.

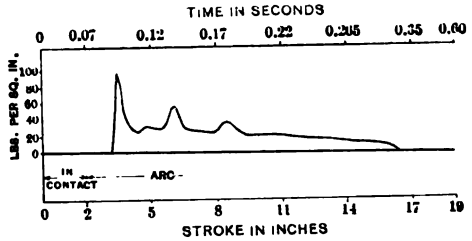

FIG. 20.—Arc length and pressure records test No. 61

There was no appreciable drop in the speed of the alternator when the short circuits were thrown on, probably due to the current limiting value of the reactances discussed later.

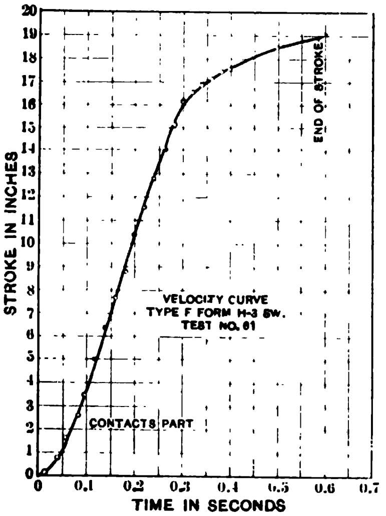

FIG. 21.—Developed velocity curve of H-3 oil circuit breaker taken during test No. 61

In comparative short circuit tests made with the throttle of the turbine open and with the throttle closed, practically the same currents were produced in the test circuit.

A number of tests were made by grounding one or all of the three phases of the circuit. In all such cases, it was noted that the effects, as instanced by the action of the oil circuit breaker under test, were very much more violent than when the short circuit was between phases. It was also noted that when the water rheostats were connected to the test circuit as an initial load, their neutral point also being grounded, the effects were very much more violent than when this initial load was absent.

At the completion of the tests, the generator was immediately placed in commercial service and is still operating, none the worse for the severe service demanded of it throughout this series.

FIG. 22.—H-3 oil circuit breaker opening during test No. 61

This goes far to show the great value of current limiting reactances in diminishing the jar on a generating equipment.

PERFORMANCE OF REACTANCES

The current limiting reactances which were used in these tests consisted of 76 turns of 1,000,000 cir. mil copper cable wound on a cement core and supported by a wooden framework. Each coil was made up in three layers. Terminals were brought out at the top and bottom. The result was a cement cored reactance having no iron in or about it. This construction was employed since the introduction of iron would not appreciably increase the current limiting value of the device. It was also found with the particular generator under test that the introduction of

6 per cent reactance in each phase halved the maximum instantaneous current and reduced the torque on the turbine shaft to about one seventh of what it would have been without the reactance. In mentioning 6 per cent reactance, it should be recalled that this refers to the drop across the reactance, which, with rated load current through it at rated frequency, would be 6 per cent of the rated phase voltage of the alternator. The reactances also maintained the terminal voltage of the alternator when a short circuit was thrown on the system beyond the reactances, and permitted the generator to recover its normal voltage after a short circuit had been removed much more rapidly than would have been the case had the short circuit been placed directly across its terminals. This makes them of great importance where a synchronous load is connected to a system since one of the two features for holding a synchronous load is the maintenance of voltage.

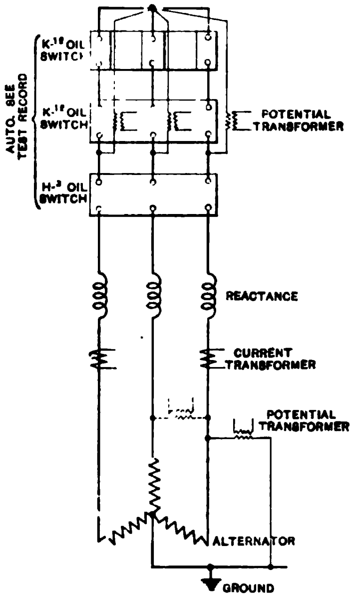

FIG. 23. -Diagram of connections for tests 171 and 173

As a result of the reduction of the torque on the turbine due to the introduction of reactances, there was practically no drop in speed when a short circuit was thrown on it. Hence, the frequency of the system was maintained at practically normal value, and this, together with the maintenance of the alternator voltage, as previously described, tended to markedly improve the operation of synchronous apparatus under abnormal conditions.

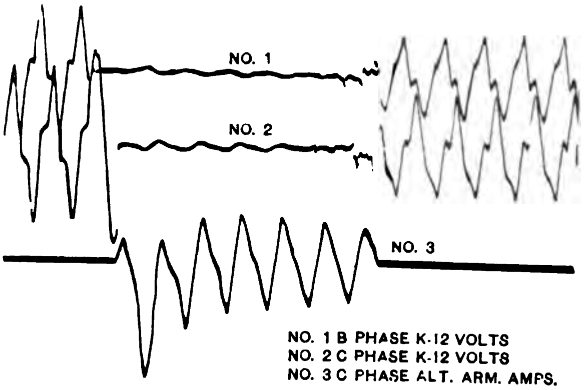

Fig. 24.—Oscillogram A test No. 171

Current limiting reactances also change the power factor of a short circuit and distort the wave form of the system as may be seen on comparing the first parts of curves 1 and 2 in

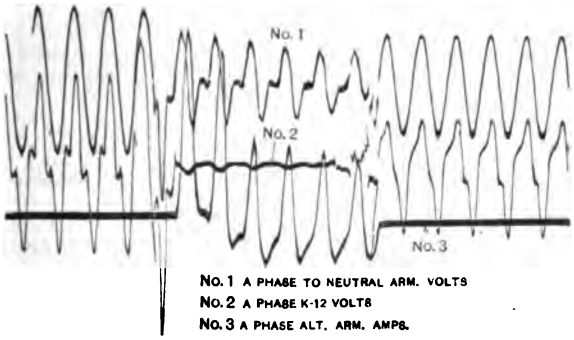

Fig. 25.—Oscillogram B test No. 171

Fig. 25. The stray fields of these reactances were not sufficient to distort the coils in any way and at a distance of several feet, iron screens were not noticeably attracted nor were they appreciably heated.

Action of Oil Circuit Breakers

In the discussion of various tests, it was noted that at times some oil was thrown out of the oil vessels. By suitable baffling, the energy imparted to the oil by the expansion and explosion of the gases generated in the oil vessels was absorbed and the operation of the circuit breaking device materially improved and its rupturing capacity increased.

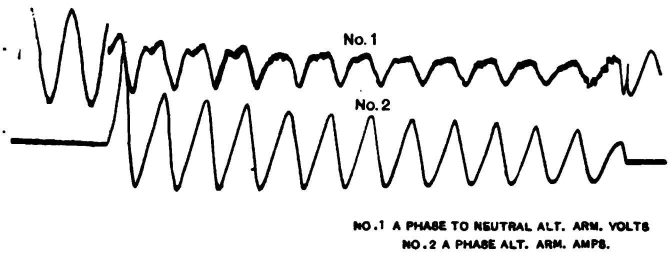

Fig. 27.—Oscillogram test No. 173

It was also found possible to separate the gases from the oil, thereby permitting the gases to escape into the air and the oil to be retained in the oil vessels.

In a commonly constructed design, a small distortion of the oil vessels permits a considerable quantity of oil to be thrown out. This, however, can be readily prevented.

It is very often found convenient to install oil circuit breakers in fire resisting compartments. By means of external oil diverters, it was found possible to direct the gases and oil thrown out of the oil vessels to the lower parts of the cells. In reported cases on other systems, gases from oil circuit breakers have been known to ignite, resulting in an explosion. Suitable baffles and diverters can be designed, however, to take care of these conditions.

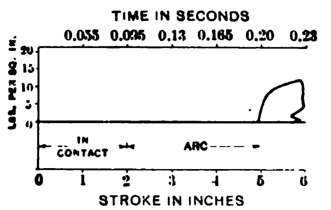

Fig. 26.—Arc length and pressure records test No. 171

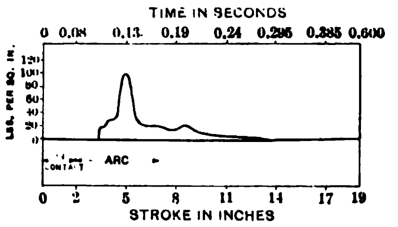

Fig. 28.—Arc length and pressure records test No. 173

In all of these tests, the temperature of the oil was roughly noted and in no case was it found to have been raised an appreciable amount after short circuit was opened. In some recent tests where successive short circuits were opened by oil circuit breakers (some times as many as six in ten seconds) it was also found that the oil did not heat appreciably. It is thought that this is due to the intensely local action of the oil circuit breaker, for, when the contacts part, the arc which is drawn produces gases which form pockets in the oil.

The larger oil vessels of the H-6 form were of greater assistance in opening a circuit. The results show that the stress developed in the 10-in. diameter oil vessel is only from one-third to one-fifth of that developed in an 8-in. diameter oil vessel of the H-3 form.

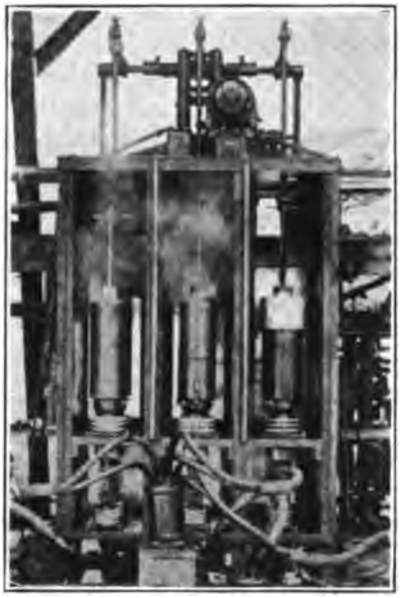

FIG. 29.—H-3 oil circuit breaker opening during test No. 173

It was found that by diminishing the velocity with which the contacts parted, there was more disturbance and the rupturing capacity of the device was greatly diminished.

The length of break is directly connected with the velocity of moving contacts. A long break is very desirable in as much as it gives a large factor of safety under normal operating conditions and a much greater rupturing capacity in emergencies.

A preliminary review of these tests shows that the oil circuit breakers opened all of the loads or short circuits without producing any external disturbances or developing any undue pressures, and their ultimate rupturing capacity was not reached. The main current carrying parts were well protected from burning by the arcing contacts and these latter were not materially injured after opening and closing numerous short circuits. The temporary cell structure, although made of inflammable materials, was not injured in any way, and practically no stresses were developed in the cells.

During some of these tests a small quantity of oil came out of the oil vessels, was deposited on the cell doors and spreading out very thin gave the impression of a larger amount. By actual measurements after a number of severe short-circuits it was found that only 5 per cent of the oil had been lost. The repeated use of the oil in the oil vessels did not appreciably diminish its efficiency and the introduction of suitably designed oil baffles and diverters overcame the tendency for the oil to come out of the oil vessels. The oil diverters and baffles experimented with can be readily applied to existing circuit breakers at comparatively small expense and with practically no changes to the original installation.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 27, 1911.

DEVELOPMENT OF THE MODERN CENTRAL STATION

BY CHARLES PROTEUS STEINMETZ

The predecessor of the huge modern central station is the Edison direct-current three-wire station, which was developed 20 years ago. By a system of feeders and mains, direct current was distributed at 220-volts from a station located at the center of power demand. When the limit of economical distribution from a single station was reached, additional stations were built, and all the stations connected by tie-lines.

Characteristic of these stations were the good voltage regulation, incident to the system of feeders and mains; the high economy, resulting from the parallel operation of all the stations and the consequent reduction of light load losses to a minimum, and the high reliability of service, which stands unexcelled even to-day, and which resulted from

a. The parallel operation of all the stations, which guarded the system in case of breakdown of one or several stations;

b. The storage battery reserve, which maintained service even at a complete shut down of all the generating stations, and especially

c. The nature of the system of low tension feeders and mains, which limited the effect of any breakdown at any point of the system to its immediate vicinity, by limiting, by the resistance of feeders and tie-lines, the power which could be concentrated at any point, to such an extent, that no local breakdown could involve, or even seriously affect the entire system.

It must be conceded that in this latter respect this low-tension system was safer than even the present modern high-voltage generating systems, and in the latter the problem of the localization of the effect of any breakdown is still the most important one in the development of the modern central station.

The most serious disadvantage of the direct current three-wire generating station was the limited distance to which power could be transmitted economically at 220 volts. This limited the use of the system to densely populated districts; as the interiors of large cities were within the economic radius of 220-volt distribution a load for a generating station of economical size could be found. It also did not permit the best economy of operation, as it required the location of the generating stations in the interior of the cities.

The limitations in the distance of transmission were soon overcome, and electric power made generally available, by the alternating-current system. As it was first developed, as single-phase high-frequency system with individual transformers at the customers' premises, it had the fatal defect of large all day losses in the transformers, and as the result, most of these early alternating-current stations were not an economical success, and the alternating-current system became economically feasible only by the introduction of the three-wire-secondary mains, fed from large transformers by primary feeders, that is, the main features of the Edison feeder and main system, from which the modern alternating current system differs only by the substitution of high-tension feeder and transformer, for the low-tension feeder of the direct-current system, and by the addition of a fourth wire or other method (as separate feeders), to take care of power distribution to motors.

The final power supply to the customers, for lighting or other domestic services, is now generally from a three-wire 220-volt main, by direct current in the interior of large cities, by alternating current in less densely populated districts. The characteristics which make the direct-current systems suited for more concentrated, the alternating-current system for less concentrated demands, are:

Reactive drop and magnetic screening are absent with direct current, and large conductors can thus be used, carrying larger currents than are economical with alternating distribution. A greater density of load can thereby be taken care of, larger power supplied over each feeder, and voltage regulation at every feeding point in the mains thus becomes economically feasible. The mains, tied together, exchange power between feeders, and thereby equalize the voltage. Storage battery reserve is conveniently feasible, with its great increase in the service reliability. For certain classes of service, as high speed elevators, the direct-current motor is further developed. However, the low-tension direct-current feeder must be carried back to a generating station or converter substation.

With alternating-current supply, 2200-volt high-tension feeders can be used, and a much larger territory thereby supplied from one station. Much lower voltage drops are feasible in the high-tension alternating-current feeders, than in the low-tension direct-current feeders, and several transformers with their secondary mains can thus be supplied, with fair regulation, from the same primary feeder, and this allows the installation of small mains of limited extent. The secondary mains may be sectionalized without serious disadvantage in regulation. The high efficiency of the modern transformer permits economical power supply in districts which can not be reached by direct current, as the load is so scattered that only a moderate amount of power is accessible to each main, and sufficient load for the economical operation of a converter substation could not be found within the economical radius of such a station.

The economic disadvantage of the location of a number of direct-current generating stations in the interior of large cities led to their replacement by converter substations, which receive their power from a large three-phase generating station, usually at 25 cycles. Thus originated the present system of monster three-phase power generating stations, which supply numerous converter substations for 220-volt underground direct-current distribution in the interior of the cities, with storage battery reserve; supply transformer or frequency converter substations for 2200-volt alternating primary distribution in the less densely populated districts, 600-volt converter substations for railway, and supply three-phase 25-cycle power direct to large motors. Reliability insurance against a serious breakdown in the generating station led to the subdivision of the power generation in two or more main generating stations, and so we see now in operation in this country huge generating stations, coöperating with each other and with smaller outlying stations, very similar in principle, though vastly greater in magnitude, than the direct-current three-wire generating stations of 15 years ago. To the former direct-current generating stations thus correspond in the present central station development not the converter substations of the direct-current distribution section of the system, but the main three-phase generating stations, and to the 220-volt feeders and tie-lines between the stations correspond the 6,600-, 9,000- or 20,000-volt power feeders from the main generating stations to the substations, and the tie-lines between the generating stations.

Comparing the modern system of high voltage three-phase generating stations, which supply power to a large city and almost to a state, with the system of low voltage direct current generating stations of old, we find, besides the vastly greater amount of power of the modern system, and correspondingly greater destructiveness of the power when beyond control, two essential differences:

a. The alternating nature of the power involves in the parallel operation of the generating stations, as required by economy and reliability, the problem of synchronizing, which did not exist with the direct current stations.

b. While in the direct current system the power, which could be developed at any point in the system, was limited by the resistance of feeders and mains, and the limited power of the generators, and an accident anywhere in the system could not seriously involve the entire system, but remained essentially local in character, in the present system the maximum power is available practically everywhere, and an accident or disturbance may be felt over the entire system. That is, the safety resulting from the locally limited power, and corresponding reliability, of the direct-current system, is not inherent in the modern high-power and high-voltage alternating system, and before the operation of the present huge systems can be as safe and as reliable as that of the low-tension direct-current systems was, means must be found to limit the power which can be developed in case of accident anywhere in the system, to a safe value, that is a value which would not seriously affect or endanger the operation of the system.

The safety of the low-tension direct-current system against general disturbances caused by a local accident, such as a short circuit, was the result of the relatively high resistance of circuits; it was however paid for by a lower efficiency of distribution, resulting from the losses in the line, such as are no longer permissible in our modern large systems, and if permissible, would not be feasible, as the distribution cables could not dissipate the power without self-destruction. However, due to the alternating nature of the power, voltage can be consumed in the modern systems, and the current limited thereby, without corresponding loss of power, by reactance; and to make our modern high-voltage high-power systems as safe against local accidents, as were the low-tension direct-current systems, power-limiting reactances must in the former take the place of the resistance of lines, feeders and mains of the latter system.

The industry has been slow to realize the importance of reactance in giving safety and corresponding reliability to high-power generating systems. The reason was a prejudice against reactance, which had survived from the early days of the single-phase high-frequency systems, in which the reactance in generators, lines and transformers had been the enemy which spoiled the desired voltage regulation. We are just beginning to realize now, that in the huge systems which use a large part of their power by synchronous machines, as converters, frequency changers, etc., reactance is not an enemy to regulation, but affords the most effective means of voltage regulation by phase control.

A considerable amount of reactance is necessary for safety, to limit the possible local concentration of power, and for voltage regulation in systems containing synchronous machines, and also for the stability of the latter, as the parallel operation of synchronous machines, whether generators, motors or converters, is possible only if the circuit between the machines contains considerable reactance.

In a station or group of stations of 100 to 200 megawatts generator capacity, in high-speed turbo alternators—and there are a number of such stations now in existence—with a momentary short circuit current of 30 to 40 times full load current, the maximum current which could momentarily appear at a short circuit on the bus bars, would correspond to from three million to eight million kilowatts. When opening such a short circuit, the power at the opening break must pass from zero at short circuit to zero at open circuit, over the maximum momentary output of the generator, which is one-half the product of short circuit current and open-circuit voltage, or from one and one-half to four million kilowatts. It is obvious that no switching mechanism can be designed which can always be relied upon to open such power, and which at the same time is sufficiently small and reasonable in cost, to employ hundreds of them in the system, on the generators, feeders, etc. Hence the insertion of power-limiting reactance in generators, busbars, etc., becomes necessary for the safety of the system.

The low-tension direct current generators of old probably gave a momentary short circuit current of three to five times full load current, and at permanent short circuit lost their excitation. The modern high efficiency turbo-alternator gives from three to five times full load current on permanent short circuit, but nearly 10 times as much momentarily. While the permanent short circuit current is within safe limits of the mechanical and electrical strength of modern apparatus, the momentary short circuit current is not, but, allowing for the advance in the art of machine design since the days of the low-tension direct current machine, a momentary short circuit current of 10 to 12 times full load current would be within safe limits. This means increasing the self-inductive reactance of the generator to 8 to 10 per cent. It can either be done by the insertion of external reactance, preferably in the phase leads, or by the design of the generator, or by both. Internal reactance of the generator of the required amount interferes with economical design, and has the disadvantage of offering no protection in case of an internal short circuit which eliminates the generator reactance, and the preferable method thus is to give the generator a reasonably high internal reactance (3 to 5 per cent) and insert additional reactance in the phase leads, of 4 to 6 per cent* Where step-up transformers or auto-transformers are used, they can be designed to afford the required external reactance.

Even when limiting the momentary short-circuit current of the generators to 10 times full load current, with the parallel operation of a system of several hundred megawatts generator capacity, the momentary short circuit power would still approach millions of kilowatts. It therefore becomes necessary in these large systems, either to operate the system in a number of separate sections, or to sectionalize the busbars by power limiting reactances.

The former is frequently done, but appears to me a temporary expedient only, and economically impracticable as a permanent condition of operation. When limiting the generator capacity per section to a maximum of 60 megawatts, three or four sections would be required in some of the existing systems. As this

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*These power-limiting reactances must maintain their reactance at short circuit. Thus, if iron is used in them, the densities must be so low that saturation is not reached with the short circuit current. With a 4 to 6 per cent reactance, this limits the iron density to $B = 500$ to 1000, and as such low densities can far more economically be produced in air, the power-limiting reactances are ironless reactances.

means a partially loaded generator in every section, a larger total generator capacity is required, and a lower economy of operation results, than with parallel operation of the entire system. Furthermore, reliability would require to supply every substation from several sections, and this would necessitate to sectionalize also every substation on the alternating side, and would thereby lower the economy of the use of feeders and substations. The necessity of providing means of throwing substation apparatus from one section to another section, in case of accident to one section, complicates the method of control and introduces the danger of accidentally connecting together in the substation feeders coming from different sections and out of synchronism with each other, with the result of a short circuit between two sections. As the complication of control would usually make it impracticable to carry feeders from more than two sections into a substation, the reliability of service would be lower than in parallel operation, when important substations could receive power from three or more power houses. The loss of economy and of reliability, and the complication of control of the system increase so rapidly with the increasing number of separate sections, that it appears to me, that the only feasible method, which permits unlimited extension of the system without any increase of danger and complication, is the parallel operation of the entire system, on a single ring bus, which is divided into sections by power limiting busbar reactances.

These reactances must be large enough to limit the power which can flow over them, so that in case of a short circuit on one section, the adjoining busbar sections are only moderately affected, the further busbar sections not affected at all; at the same time, the reactances must be sufficiently low and of sufficient capacity, that any amount of current, which during a change of load a busbar section may draw from the adjoining busbar sections, can be safely transmitted over the reactances without any voltage drop, by a slight phase displacement between the adjoining busbar sections. With a capacity of 50 to 60 megawatts per section, a permanent carrying capacity of each busbar reactance, of two megavolt-amperes, at 15 deg. phase displacement, and a power limit, in case of a short circuit on one section and full voltage on the adjoining section, of 40 megavolt-amperes appears at present the best compromise. The ring bus, into which all the generators G of the system feed, would then comprise the busbars B of the various power houses, H_1, H_2 ..., and the tie-lines *L* between the power houses, as indicated diagrammatically in Fig. 1, in which x denotes the power-limiting reactances in the generator leads, x' the power-limiting busbar reactances, *F* the feeders which issue from the busbar section, and *C* denotes the non-automatic, *A C* the automatic circuit breakers in the system.

Coming now to the consideration of the feeders which issue from the generator busbars. In the low-tension direct current system, the effect of a short circuit in a feeder—if not extremely

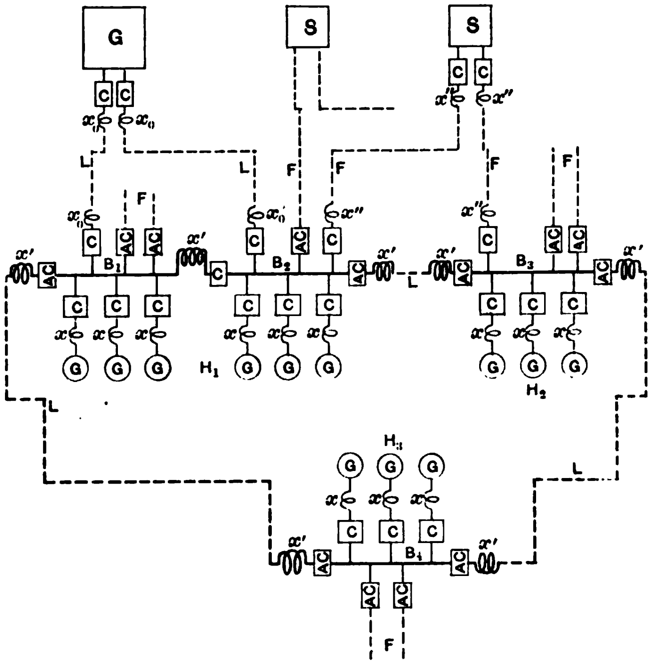

Fig. 1

close to a generating station—was limited by the resistance of the feeder. With the modern high-power alternating system, the feeder resistances are very low, and a short circuit in a feeder is almost a short circuit on the busbar. While generator reactances and busbar reactances greatly limit such a short circuit, there still remains the disadvantage, that nothing limits the power which is available locally on a feeder, below that available on the busbar to which the feeder connects, and in this respect the modern system is inferior to the old low-tension direct-current system. The safest method would be to limit the available short circuit power of every feeder by reactances at either end of the feeder, in the generating station and in the substation *S*, as indicated by x'' in Fig. 1. This method, which would make the modern high-power system as safe as the former low-tension direct-current system, has not yet been considered, since unfortunately the development of the alternating part of the present system has started from the experience of the small alternating systems of old and not from that of the low-tension direct current system, and in the former, the limited power of the generating system, combined with the relatively high reactance of the overhead feeders, made power limiting reactances in the feeders unnecessary. Instead of limiting the power, automatic circuit breakers are provided in the feeders, as indicated by *A C* in Fig. 1, which instantaneously cut off the feeder in case of short circuit. This method has been very successful, and with the limitation of power by the reactances in busbars and generators, appears sufficiently safe, but still has the disadvantage of momentarily exposing the busbar section and the feeder switches to the shock of short circuit in case of a failure of the feeder, and it may thus well be considered, whether a safer way of operation would not result from limiting the power of the feeders by reactances and then hold on to the feeder in case of a fault, until the fault either clears itself, or the feeder has to be cut off, that is, in other words, to return, even in this last structural element of the modern station, to the well tried principle of the low-tension direct-current system.

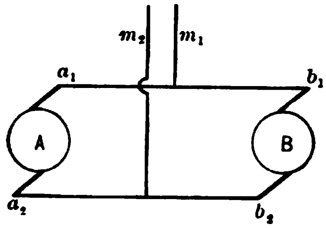

FIG. 2

In the parallel operation of the individual generators, and the entire generating station of the modern high voltage alternating-current system, a problem is involved, which did not exist in the direct-current system, *viz.*, synchronizing. The general problem of synchronous operation is well understood and is as follows:

If two machines, *A* and *B* in Fig. 2, (whether generators, synchronous motors, converters or frequency changers) shall run in synchronism, the constants of the circuit between the two machines, $a_2\ a_1\ b_1\ b_2$, must be such that any phase displacement (that is, position displacement) of the two machines causes a current to flow between the machines, which accelerates the lagging, retards the leading machine, irrespective whether in addition to the exchange or cross current between the machines, the machines also send out current, or receive current from the outside, at m_1 m_2. If the two machines are exactly in step, in the local circuit a_2 a_1 b_1 b_2, the voltages of the two machines, are in opposition, as shown by *a* and *b* in Fig. 3. Thus there is no resultant voltage, and no current flowing between the machines. If now the two machines are slightly out of step, and *B* lags slightly, that is, its voltage reaches the maximum at a slightly later time, *b* in Fig. 4, and *A* leads slightly, that is, its voltage reaches the maximum at a slightly earlier time, *a* in Fig. 4, the two voltages *a* and *b* in Fig. 4 give a resultant, which reaches its maximum midway between *a* and *b*, as shown as *c* in Fig. 4. This resultant or cross voltage of the two machines produces a cross current circulating between them. If now the circuit between the two machines, a_2 a_1 b_1 b_2, should contain only resistance, but no reactance, the cross current *i* would be in phase with the cross voltage *c*, as shown in Fig. 5. It would then be practically in quadrature with the two machine voltages *a* and *b*, that is, would be a wattless current in the two machines, neither consume nor produce power, that is, there would be no synchronizing power.

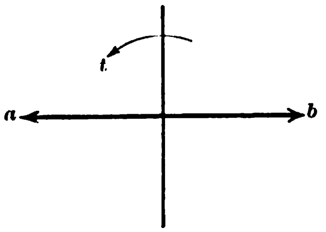

FIG. 3

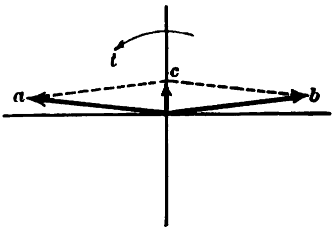

FIG. 4

Assume now that the resistance of the cross circuit is negligible compared with the reactance, then the cross current *i* would lag nearly 90 deg. behind the cross voltage *c*, which produces it, as shown in Fig. 6. Thus it would be approximately in phase with *a*, approximately in opposition with *b*, and would thus consume power in the leading machine *A*, that is, retard it, and supply power to the lagging machine *B*, that is, accelerate it, and thus pull the two machines together, as synchronizing current. Hence, the reactive or quadrature component (with regard to the cross voltage *c*) of the cross current is the synchronizing current, and the power component of the cross current exerts no synchronizing power. Thus, reactance is necessary for synchronous operation, and the larger the reactance is, compared with the resistance of the cross circuit, the larger a part of the cross current is synchronizing current. Increasing reactance therefore increases the synchronizing power. There obviously is a limit hereto: with increasing reactance, the cross current decreases, and while the percentage of the cross current, which is synchronizing current, increases, the absolute value of the synchronizing current, and with it the synchronizing power, again decrease.

For stable parallel operation of synchronous machines, a reactance of the cross circuit thus is required, which should be at least twice the resistance of this circuit.

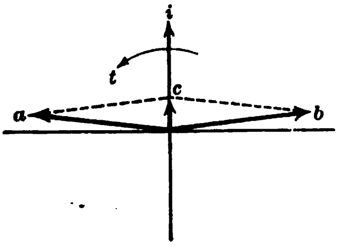

FIG. 5

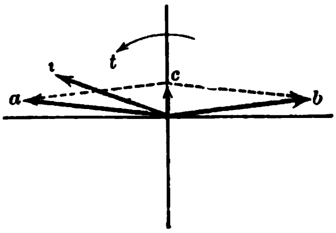

FIG. 6

Of the synchronous reactance of an alternator, essentially only the true or self-inductive component comes in consideration in synchronous operation, as the armature reaction component is usually too slow to exert itself. In steam-turbine alternators, the self-inductive armature reactance is very low, frequently only 2 to 3 per cent; however the armature resistance is a fraction of one per cent, and when connected to the same busbars, synchronous operation of such generators is satisfactory. A few per cent of resistance between the turbo alternators, as may exist when operating two power houses together over a tie-line, makes synchronous operation unstable or impossible without the insertion of a corresponding amount of reactance. This is to be kept in mind in the parallel operation of power houses, the more as the tie-lines are usually underground cables, and as such have practically no reactance. With power-limiting reactances in the generator leads, obviously a much higher resistance in the tie-lines between power houses would be permissible before parallel operation becomes impaired and additional reactance is required.

Parallel operation of synchronous machines thus requires reactance in the circuit between the machines. It is further required, however, that the combined effect of resistance and reactance, that is, the impedance of the cross circuit, is sufficiently low to allow a large enough current to flow to keep the machines together against any tendency which separates them, as inequality of the driving power, slighly different speed adjustment of the engine governors, etc. That is, the possible cross current between the machines must be comparable in magnitude with their full load current. This however is frequently not possible in the parallel operation of power houses distant from each other, over tie-lines. The capacity of the tie-lines between big power stations would economically be proportioned to the required exchange of power, and thus usually would not be sufficient to pull the two stations together into synchronism. Here, then, a new problem arises which was not met previously in synchronous operation of alternators: the engine or turbine speeds of the two stations must be controlled, independently of the alternators, so as to be so closely the same under all conditions, as to require a very small synchronizing power between the alternators, to pull into step and remain in step. That is, as we may express it, the prime movers must be synchronized. While this had not been done before, it is a mechanical problem, which electrically can be solved without serious difficulty, for instance, by controlling the governor in the steam supply by the power exchange between the stations, in combination with sufficiently powerful dash-pots, to guard against governor hunting.

An important application of this problem of electro-mechanical synchronizing will occur in the parallel operation of outlying stations, with the main station.

For instance, if at the end of a long feeder the power demand increases so greatly as to warrant the installation of a moderate sized station—one or two 2- to 5-megawatt turbo alternators—economy and reliability of operation would require this outlying station to be paralleled with the main generating station, so as to use the main station as reserve; and the economical method of operation would be to run the outlying stations as nearly at constant full load as possible, and take care of the load fluctuations by the main station, over the tie-lines, to get the benefit of the diversity factor of the entire system. This usually means not only a fluctuating flow of power in the feeder from the main station to the outlying stations, but often also a reverse flow. Voltage regulation at the outlying stations then can be accomplished only by phase control of the feeder, through reactances, as indicated at x_0 in Fig. 1, and with the increase of the outlying load the feeder capacity very soon would be insufficient to pull the outlying stations into step, and mechanical synchronizing, as discussed above, becomes necessary. We must realize, that in the direct line of the modern central station development is an extension of the power supply to that of an entire state or a number of states, from a few huge main stations near the centers of power demand, and numerous smaller outlying stations, with the entire system operating in synchronism through feeders and tie-lines, in which the power flow fluctuates in amount and in direction, and of which very few are sufficient to pull stations together into synchronism, but just sufficient to keep them in synchronism, if the speed regulation of their prime movers is independently maintained very closely the same.

These then are the two problems before the modern central station: The localization of any disturbance by power limiting reactances, and the synchronous operation over lines of limited power, by speed control of the prime movers.

DISCUSSION ON "THE USE OF POWER LIMITING REACTANCES WITH LARGE TURBO-ALTERNATORS," "SOME RECENT TESTS OF OIL CIRCUIT BREAKERS" AND "DEVELOPMENT OF THE MODERN CENTRAL STATION." CHICAGO, JUNE 27, 1911.

John W. Lieb, Jr.: Once again we are indebted to Dr. Steinmetz for a splendid and acute analysis of what is essentially a practical problem. With that keenness of discernment which we have been accustomed to expect from Dr. Steinmetz, he has touched upon a number of vital points which are of momentous interest to the present and the future of central station work. In the papers of Messrs. Schuchardt and Schweitzer, and in the paper of Mr. Merriam, we have notable instances of the method of applying scientific research to the investigation and solution of electrical problems, and the Institute is to be felicitated in having before it the details of these tests as affording material for thought.

In Mr. Schuchardt's paper he refers to the points to be determined by the tests which were made, indicating as the first, the instantaneous short circuit current of turbo-generators without external reactance. These questions referred to by Dr. Steinmetz and the other authors are matters which have been given careful consideration by the New York Edison Company, for instance, as another of the companies having these large problems to deal with, and this first element was one of the first questions which presented itself for investigation; and it was found that there was a considerable and wide variation as between types of generators, particularly turbo-generators, in this matter of internal reactance. There were tests made between types of generators as to the amount of internal reactance, amounting to as great a difference as two to one. It has therefore, opened a new light as to the possibility of control within the generator itself of the application of an increased amount, by and within the practical limitations which the applications permits, of internal reactance, and by an increase of internal reactance you make it possible to limit the amount which need be applied externally.

It is difficult to conceive of the tremendous disturbance that takes place on a large interlaced system by short circuits in feeders or failure of generators. With ten, twenty, or thirty substations distributed over vast areas, having hundreds of synchronous machines working in parallel, the disturbance and throwing out of synchronism of this vast number of units, and the enormous difficulties involved in starting up these different substations widely separated, present unique problems, and it is therefore well worth most careful consideration to reduce the possibilities and the effects which these enormous concentrations of power in local disturbances may call forth.

The concentration of power for economical reasons in these huge power plants, the dependence for vast industrial enterprises and for our transportation systems, as well as for lighting and industrial power, make it absolutely essential that they shall be protected against disturbance, and that every possible precaution should be taken, which experience or ingenuity can provide, against irregularity in operation, because if these huge systems are going to be subjected to disturbance and interruption of service, we shall have reached a point where something radical will have to be done; but very fortunately with these elements which are brought before us, and other elements which are not here referred to, we can feel sure that the future provides fairly safe guarantees against interruption of service which produce very serious results in a community served by these vast enterprises. I am sure that we are very much indebted to the gentlemen of the Commonwealth Edison Company for having laid before us in great detail the results of their tests and experiments, with a view to arriving at a satisfactory solution of these problems, and to Dr. Steinmetz for having put his finger on the essentially important elements which are such prime factors in the development of the modern central station industry.

M. H. Collbohm: Mr. Merriam has presented us with very valuable data on the operation of oil switches designed for severe service conditions which data have been obtained from actual tests.

I note, however, that all these tests have been made on an oil switch type employing the vertical break. It would have been very instructive if the test had also been made on a switch of the horizontal break type in order to allow comparison between these different constructions.

It seems to me that the horizontal break oil switch would offer greater prospects for successful operation under severe conditions for the following reasons:

1. The break occurs in the lower part of the tank with a considerable head of oil above the break, in contradistinction from the vertical break where the arc starts nearer to the surface of the oil. This seems to be of great importance considering that the arc is most vicious at the moment of separation of the contacts when the current has its greatest value.

2. The horizontal movement of the thin switch blade through the oil combined with the tendency of the arc to rise vertically causes this arc to continually come into contact with fresh and cool oil layers thus extinguishing the arc sooner than would be possible in the vertical break switch where the arc tends to maintain its original vertical position. The break in the vertical type must therefore be considerably longer thus rendering this type of oil switch materially more expensive for the same rupturing capacity.

3. The knife blade form of contact pieces insure a more positive contact in the clips than can be obtained by the wedge or butt contacts usually employed in the vertical break switch for higher voltages.

The speaker has had experience with both types of switches on high tension lines and feels it his duty to express his satisfaction with the cheaper horizontal break oil switch which has opened without trouble several short circuits without the dampening influence of reactive coils.

The main advantage claimed for the vertical break type, *viz.*, the opening by gravity does not seem to the speaker to be superior to the opening by springs. The latter can be adjusted for a more rapid operation thus increasing the effectiveness of the switch. The gravity break type in the speakers experience in one instance failed to establish good contact in closing resulting in the partial burn off of the contact clips and carbonizing the oil.

In regard to the rupturing capacity of the oil switch in general I would like to be informed what the considerations are for giving the same switch type a higher rating on lower voltage than on higher voltage, as given by some manufacturers, catalogues. Ordinarily one would expect greater damage to the switch at lower voltage due to the greater $I^2 R$ energy in the rupturing arc. The speaker in laying out the switchboard for a 16,000-kw. hydroelectric station interconnected with others of still higher rating, suggested the use of a high generator voltage in order to lessen the possibility of trouble to oil switches under short circuit conditions but was informed by the switch manufacturer that the standard voltage of 2,300 volts would be preferable.

As the speaker at that time could not get a satisfactory explanation for this advocating a lower voltage he would appreciate very much to learn at this time the reason for this method of rating oil switches.

Dr. Steinmetz in his paper has given a very interesting exposition of the development of the present alternating current central station from the old direct current plant with particular reference to the external reactance coil as one of the characteristic protective features of the modern large sized plant. The development of this protective device was brought about by the desire to overcome the danger from the enormous short circuit current in the system, particularly in a plant with synchronous turbo-generators.

The question arises in my mind whether this heavy short circuit current could not be materially reduced by other means, possibly in addition to the proposed choke coil. The present practice of sacrificing regulation in the synchronous machines in order to reduce the short circuit current, is only a small help, and it seems that the liberal use of induction generators with their characteristic low short circuit current would aid very materially in bringing about the desired result, both as regards reduction in short circuit current as also absence of necessity for running synchronized.

This type of machinery has already been successfully installed in combination with low pressure steam turbines, and it seems that the equipment of a whole station with induction generators specially designed for a small magnetizing current in connection with synchronous motors floating idle on the system for furnishing this magnetizing current would make a feasible arrangement. The synchronous motor in such installations would have the appearance of an unproductive piece of apparatus, but for the advantage it offers by rendering the respective plant independent from any other synchronous station, its use appears justified. It might thus be considered to be in a same class with the frequency changer.

In such a system the throwing together of stations slightly out of phase may not cause nearly as heavy a shock as if both stations were equipped with synchronous machines only. The last problem stated by the author at the end of his paper, *viz.*, synchronous operation of different stations would then also find its solution.

Aside from city steam stations this induction generator type would also be of considerable advantage in a system of interconnected hydroelectric plants where it could be installed at stations of secondary importance, furnishing power only and leaving the regulation of the system to a synchronous generating station. The installation of a synchronous motor in connection with the induction generators would again render this secondary plant independent from the main station as regards regulation. Such a plant could always be run at highest efficiency, possibly without the use of hydraulic governors and could utilize the total stream flow at nearly all times without the expensive provision of a storage reservoir.

Aside from the development of the reactive coil as a protective feature of a high capacity low tension steam station there have been made developments on other protective devices serving a different purpose in stations of high voltage character, and which may perhaps properly be mentioned in discussing station development:

The aluminum arrester, although it has failed several times in the speakers experience to perform its function without being destroyed itself by mere internal disturbances in the system, represents nevertheless a considerable improvement over the older types.

In addition to the use of this arrester the speaker has advocated and put into successful operation a scheme of additional protection to station apparatus consisting in the use of solid non-coated iron wire of high permeability for station wiring, extending from the high tension transformer taps to the point where the arrester connections tap on the transmission line, which should preferably extend to the first tower outside the power house. The advantage of this scheme lies in the greatly increased ohmic resistance which the iron wire, due to the skin effect, offers to any high frequency surge such as lightning. The choke coil in particular, representing quite a length in the conductor, should be of soft Swedish iron. This scheme of using iron wire choke coils appears also to get into favor in Europe judging from a bulletin of a responsible European manufacturer of such coils recently received by the speaker.

The usual danger from high voltage building up on the reactance of the series transformer by any high frequency disturbance has been overcome by an arrangement of the speaker of shunting a small electrolytic cell across the high tension terminals of the series transformer.

Inasmuch as the skin effect of the iron wire was sought as an additional choking effect for protecting station apparatus, it had on the other hand to be removed from the path of the lightning discharge, particularly the overhead ground wire on the transmission lines was investigated by the speaker in 1909 with the result of recommending copper clad steel for ground wire purposes instead of steel which had been used exclusively before. Subsequent high frequency tests made at the University of Wisconsin on iron and copper wires have proven the speaker's arguments in favor of copper.

All the before mentioned schemes for additional protection to station apparatus have been tried out on one of the hydroelectric transmission plants built by the speaker and have worked out to entire satisfaction. This particular plant (of the Northern Hydroelectric Power Co. at High Falls, Wis.) has experienced many severe lightning storms which caused the arresters to act very frequently but there has never been the slightest damage to any of the apparatus.

A further development in lightning arresters has recently been made in Europe where a number of prominent central stations have been equipped with arresters consisting of one or more banks of condenser elements shunted by a grounding choke coil. The condenser battery acting on high frequency disturbances of any voltage, even of a very low value to which the electrolytic arrester would not respond, while the choke coil takes care of accumulated static. This arrester is reported to have given excellent results.

There are some minor details which have recently undergone development and which when taken as a whole may exert a marked beneficial influence upon the safety of central station operation.

The instrument and control panels in a large station become so numerous as to be difficult to oversee, and a reduction in their number and a clear distinction between the various instruments and panels becomes very desirable. The voltmeter and ammeter for the generators may be omitted from the respective panels and one instrument of each kind placed on a swinging bracket to serve for all the various machines by providing a receptacle and plug for each of the respective panels. A wattmeter and power factor indicator is generally sufficient for the control of the generators. If curve drawing instruments are used they may serve at same time as indicating instruments thereby rendering this latter instrument superfluous. A duplicate transmission line may be equipped with one wattmeter only by paralleling the secondaries of the respective current transformers.

The panels and the instruments should preferably be black and the instruments have their designation printed in bold types upon their scales, such as " Volts—Amperes—Watts, etc.," the graduation of the scales should be in decimals to facilitate reading. Only instruments with flat glass covers should be used to avoid the disturbing effect on the curved glass covers of the usual horizontal edgewise instruments. The illumination for the board should be accomplished by diffused light from well above the board in order to have no reflex whatever from the instruments.

The individual panels should be marked by genuine enameled name plates which do not oxidize or fade as in the case of the usual copper or paper name plate. Each circuit or group of circuits should be provided with a blue signal lamp above the board to operate in conjunction with the alarm bell in order to indicate immediately the circuit in trouble.

The above precautions may appear insignificant to the designer but they are of real value to the operator and consequently to station safety.

Besides in the Central station proper there have also been made developments in other parts of the system notably the transmission line. I wish to mention only the flexible type of transmission tower and quite recently the appearance of the composite transmission cable consisting of aluminum or copper strands and a steel center of very high elastic limit. By this arrangement the elastic limit of the composite cable is considerably increased, allowing of a wider spacing of towers with consequent reduction of cost in line construction.

D. B. Rushmore: In the President's Address this morning and in the papers which have been presented, we have the problem of disturbance from increasing magnitude—a problem most universal in the present age in social, political, industrial and engineering life. In designing for any particular condition, a design is made to meet the major point under consideration. We design machines, power plants and power transmission systems for operation, but a compromise must always be effected in considering the factors involved when we take into consideration the emergency conditions.

In the discussion that we have had on these conditions of central station operation are involved one example of a change taking place in power transmission systems, and in what are becoming very large stations for industrial power use. The magnitude of individual pieces of apparatus is increasing, the magnitude of stations, and of systems, and very largely of a number of stations tied together. While in so many of our old problems the boy, as it were, has been relatively harmless, the young man as he appears now, older, larger, stronger, and more powerful is becoming a more disturbing factor, and we have yet to look ahead to the full grown man, to the power systems that are going to cover very much larger areas than at present, and be of very much larger capacity.

In designing apparatus for these conditions a compromise is necessarily effected, and the illustration we have had of placing reactance outside of the machines, allows in many cases a better machine to be designed. While the machine has to be designed for operation, occasionally the best of machines have to be repaired, and to place a large internal reactance in machines involving high, true self induction means, as a rule, increased difficulties in repairing machines.

To bring before the Institute one problem as yet unsolved, we have had for years in hand the development of an automatic resistance which will protect the circuit against high voltage. This has been done in the aluminum lightning arrester, which in itself essentially is an automatic resistance varying with the voltage. What we need now is an automatic reactance varying with the current, something not yet obtained, and something which is well worthy of the best study of inventors. I think that such a thing is possible, as well as likely. It has not yet been developed with sufficient rapidity to handle the problem of these large instantaneous short circuits. We must also consider that any change in condition is to be met with other changes and in connection with systems possessing large capacity or induction, all additional reactance brings with it certain possibilities which ought to demand a very much larger use of protective apparatus.

C. W. Stone: Last year at a meeting the point was raised in regard to the ultimate capacity of oil switches. In the paper by Mr. Cheney of Philadelphia, there was some question raised about the ultimate capacity of oil switches, and the suggestion was made that it was possible that we would need a new type of switch in order to handle these large capacities. I think the paper by Messrs. Schuchardt and Schweitzer demonstrates that by the use of reactances and the use of the larger 10 in. oil pot switches we do not need a complete redesign of the switches. The switches are large enough even to handle such systems as the Commonwealth Edison Company, and instead of being limited by the switch, it is perfectly possible to still increase the ultimate capacities of our stations.

Before I stop, there is one thing I think I should bring out, and that is I think we owe a very great debt of gratitude to the officials and engineering organization of the Commonwealth Edison Company for the very thorough way in which they have carried out these tests. There are very few places in the country where such a complete and fundamental investigation of the shocks to systems under short circuit could be made as thoroughly as they were made by the engineers of the Commonwealth Edison Company in Chicago, and I think that the whole engineering profession should feel a debt of gratitude for this paper by Messrs. Schuchardt and Schweitzer, reporting on these tests.

Mr. Merriam in his paper points out that with the 10-in. oil pot the strains or pressures are reduced to about one-third or one-fifth of what they were with the 8-in. pot. I think that is a fundamental point. One of the previous speakers mentioned the possibility of using a horizontal break. I think he lost sight of one of the fundamental principles which has been employed so generally in the type of switches described in the paper and that is by using the vertical break, it is possible to so adjust the baffles in the switch as to confine the pressures arround the arc, and thus extinguish it more readily. This is difficult to do in a horizontal break type of switch. I think if the engineers here give this matter attention, they will be convinced that the vertical break, with the type of baffling usually employed, has greater possibilities for large capacities than any other type yet proposed.

There is another point. Mr. Merriam in his paper refers to the small amount of oil which is thrown out after repeated short circuit. I think many engineers in witnessing some of these tests would have said that the amount of oil thrown out was excessive. Complete tests were made to find out how much oil could be thrown out, and the switches were opened under short circuits time after time, without changing the oil, and then the amount that had been thrown out was measured and it was found that only about five per cent had been thrown out. To be sure, it is not a dangerous amount, and yet it does demonstrate that it is adv'sable to install these switches in fire-proof compartments, such as brick, concrete or soapstone.

Mr. Lieb brought out the point about the possibility of the increase in the internal reactances in the generators. It is perfectly possible to design generators with higher internal reactance, but you will always sacrifice something.

I do not think that a generator with twice the internal reactance of the present machines, such as those under test, would have as big a factor of safety as the generators which are now in operation. I think also the point should be brought out that the high internal reactance generators will not accomplish what the generator with the external reactance will accomplish, and that is this—with the external reactance, in case of damage to the generator, due to the breakdown of some coil, the amount of short circuit current which can flow into the generator is limited by the reactance which is in series with it. If the generators were built for high internal reactance, and external reactance not used, the effect of the internal reactances on the generator which was damaged would be entirely eliminated, and the amount of short circuit current which could flow into that generator at that time would only be limited by the internal reactance of the other machines operating in parallel.

I think, therefore, what we should aim to do is to make the generators as safe as possible, and then protect them and the system and the oil switches by means of the external reactances.

I think another very interesting point brought out by Messrs. Schuchardt and Schweitzer is that after repeating short circuits, nearly 150 of them, there was absolutely no damage to the generators, no displacement of the coils, no displacement of the field structure or the shafting of the machine. I think that demonstrates the desirability of the reactance about as well as any point that has as yet been brought up.

B. G. Lamme: Two of the papers presented this morning have brought out the fact that reactances are advisable in the protection of large capacity alternating current generators. I fully agree with the authors of the papers on this point and have held a similar opinion for several years. Experience shows that, in commercial operation, sooner or later short circuits will occur on all generating systems, especially if they are of high voltage; and if the machines are of very large capacity the stresses exerted by the short circuit current will be so great that there must be some means provided for limiting the maximum current.

An interesting point to me in the paper by Messrs. Schuchardt and Schweitzer is the amount of reactance which they found advisable. From their tests they found that a reactance which limited the maximum current to 14 times normal was satisfactory. That is an interesting figure, for it is the one which we had reached as the limit, in our experience with large generators. We found that when we could keep the current down to 12 or 14 times normal current on dead short circuit there was very little, if any, difficulty in bracing the end windings to stand the shock. We also found that, in a great many cases, there was no difficulty in getting that amount of reactance in the machine itself without making an abnormal design.

However, that question depends somewhat on other features than on the construction of the winding itself. The speed comes in as an important condition. For instance, if you have a moderate speed turbo generator of large capacity it may require an abnormal design to obtain a high reactance inside the machine itself. If you double the speed, and thus cut the number of poles in half, you may find it difficult to obtain a low reactance in the machine. As the speed is increased and the number of poles is decreased the reactance naturally tends to increase and if the speed is made sufficiently high the machine can have sufficient reactance in itself to limit the short circuit current to a satisfactory value. That being the case, no external reactances will be required in such machines. For example, if a 10,000 to 15,000 kw., 25 cycle machine is made with two poles, 1,500 rev. per min., the internal reactance would naturally be very high. Also, if the same capacity machine for 60 cycles has four poles and operates at 1,800 revolutions, a fairly high internal reactance can readily be obtained. My experience with such machines has been that there is little or no occasion for adding reactances outside the machine.

Furthermore, in these high speed machines it does not appear to complicate the machine, or increase its cost, to obtain sufficient internal reactance. In such machines a comparatively small number of coils of large size will naturally be used and such construction tends at once toward high reactance.

One fact, which should be considered in the use of reactance, is that the higher the reactance in circuit the higher the machine will be worked for a given terminal voltage, or the lower the terminal voltage with a given generated e.m.f. In other words, the addition of reactance in the circuit directly tends to decrease the available output of the machine.

On the other hand, the conditions which tend toward increased output in the machine itself also tend toward increased internal reactance, relatively, and it may be assumed that, if the machine is constructed for high internal reactance, in many cases it can also be constructed for very high output. This interrelation of high internal reactance and high output can be illustrated in a rather simple manner. Assume, for example, that with a given number of armature slots, the ampere turns per slot can be doubled, by changing the proportions of the slots, and by various other arrangements. It is obvious that the reactance of the machine as a whole would either be increased slightly, or at least, would not be decreased. However, the output would be very materially increased and in consequence the maximum short circuit current on the machine would either be decreased or would be no greater than before, while the normal current would be increased. In consequence, the machine with increased output would have no worse short circuit conditions than before, or the conditions might even be materially improved due to increased reactance. The problem therefore turns purely upon questions of design, such as obtaining high ampere turns per slot, while at the same time avoiding excessive eddy current losses and heating in the slot conductors. Greater refinements in the proportioning of the windings are now being carried out than were thought necessary only a few years ago.

For parallelling large alternating current systems, low reactance is not a necessary condition, but relatively low resistance is required. Experience has shown that there is a certain limiting resistance which can be used, above which instability of operation will occur. The limiting value of that resistance is, to a certain extent, a function of the construction of the machines themselves. For instance, if the synchronous machines have large cage dampers on their fields, the resistance between the machines can be higher than with undamped machines. In some tests made a few years ago it was found that with an ohmic drop corresponding to 20 per cent of the terminal voltage of the machine, instability was reached with the very best damper which could be put on the field. With less damping action a lower resistance produced instability. If, therefore, a 25 per cent to 50 per cent overload condition is to be considered, then at normal load, only from 10 per cent to 12 per cent ohmic drop is permissible between the machines.

At the same time that the above tests were made for limiting resistance drop it was found that a very high reactance could be used between the machines without producing instability. The tests showed that the amount of reactance permissible was far greater than that required to limit the maximum current to a safe value in case of short circuit.

There is one point not brought out in Mr. Schuchardt's paper and that is that the damage to the winding is not merely a function of the maximum current but is also dependent upon the duration of the short circuit and also upon the number of short circuits which may occur. In connection with the New Haven Railway generators, where we had to add reactances to reduce the shocks on the machines and system, it was found that an individual short circuit apparently produced but little damage to the armature windings, but in the preliminary operation of the system, as many as 25 to 30 short circuits occurred per day, and, even with such frequent short circuits, the winding was found to stand up for months before a breakdown would occur. Also, as these machines were equipped with very heavy dampers the maximum short circuit current would hold up to practically highest value for 25 to 30 alternations, which was found to be a much more severe condition than where the short circuit was of much briefer duration. The results indicated that it was the continued hammering of the insulation by the short circuit stresses which did the most damage, and not the individual shock.

A remedy applied for this condition on these machines was the use of reactances in the circuits from the machines. These were of the iron-core type and have proven very effective. At normal load the iron is worked at such a low induction that the maximum current on short circuit will just about saturate the core. When so proportioned, an iron reactance is apparently as effective as an air-core reactance and has very little external stray field. I will say, however, that in constructing this reactance a large internal air gap is allowed—about 5 in., so that it is, to a certain extent, an air-core reactance with an iron enclosing circuit.

In these New Haven machines it was found that a reactance allowing 15 times normal current was not sufficient to protect the machines, and it was necessary to put in reactances sufficient to reduce the current to seven or eight times normal. However, the conditions were abnormal, as the output of the machines was single-phase current which required heavy cage dampers on the rotor fields in order to suppress the magnetic pulsations due to the single-phase armature reaction. With these heavy dampers the short circuit conditions were very much worse than those encountered in ordinary generators of the same capacity. Experience with other types of machines has indicated that if sufficient reactance is supplied either internally or externally, to limit the current to about 12 times normal, it will protect the usual types of machines.

W. L. Waters: The tests made at the Commonwealth Edison Co., and the system of protection there worked out, are similar to those carried out three years ago by the Westinghouse Company, in connection with the Cos Cob Power Station of the New York, New Haven and Hartford R.R. Co. At the time the single phase equipment was being installed, this power house was subjected to a continuous series of short circuits due mainly to the non-selective action of the circuit breakers; these short circuits sometimes occurring as frequently as 25 or 30 per day, and varying in intensity from a dead short circuit to one at the end of a line having 5 per cent resistance drop. The system of protection worked out for that power station was:—an improved system of armature coil bracing on the turbo generators; the connection of a 9 per cent iron cored choke coil permanently in series with the line; and series or relayed oil switches, which in cases of short circuit introduced resistance into the line, thus decreasing the magnitude of the short-circuit current and raising its power factor before finally opening the circuit. This selective circuit breaker action and somewhat elaborate system of protection was installed on account of the exceptionally severe conditions of operation, and it is probable that some less complete arrangement such as that employed by the Commonwealth Edison will afford ample protection for the average power station.

Fig. 1

The system of armature coil bracing for the turbo generators is shown in the accompanying illustration Fig. 1. It will be seen that it consists of heavy wood blocks clamping the winding to metal brackets by means of insulated bolts. This bracing can be made as rigid as desired, and has the advantage of being permanent, as it does not deteriorate with time like the rope or twine lashing sometimes used. Numerous tests have been made on generators equipped with this system of bracing, by short circuiting when excited to 30 per cent above normal voltage, and in no case has any movement of the coils been noted. In fact the shock of the short circuit seems to be felt more on the frame of the generator than on the winding.

The Westinghouse tests above referred to, which were oscillograph records made to determine the effect, on the generator short circuit current, of including various types of self induction in the circuit, were made in 1908 on 2,000 kw.; 500 kw. and 300 kw. generators, tests being made at 60 and 25 cycles, both with and without dampers on the field magnets. The majority of the tests were made single-phase as it was found impossible to obtain consistent results on three-phase tests because of variation in the time of closing for the short circuiting switches in the three phases. The results of tests checked up well with theoretical calculations; the actual shape of the short current waves being found to be dependent on the power factor of the short circuit and the phase of the current at the instant the short circuit was closed. Under the worst conditions, the current wave immediately after closing the short circuit lay entirely on one side of the zero line, and the maximum peak had a value double that figured by dividing the e.m.f. of the generator by the impedance in circuit. Under the most favorable conditions, the current wave was at all times symmetrical with regard to the zero line, and the maximum peak was approximately the same as the value obtained by dividing the e.m.f. by the generator by the impedance in circuit.

Referring to the relative advantages of auto-transformers, iron choke coils, and air choke coils, for installation in a power station to protect against lightning, surges, and short circuits, it would seem that they all have both advantages and disadvantages; provided in all cases any iron cores used are worked at a sufficiently low magnetic density, so that they do not become saturated at the maximum peak of the short circuit current. An auto transformer, if built with a sufficiently high leakage reactance will undoubtedly afford protection, but it is expensive and is a constant source of loss. A 12,000-kw., three-phase, 25-cycle 4,500 to 9,000-volt auto-transformer will have a full load efficiency of about 99.25 per cent, while the efficiency of a 12,000 kw. 9,000-volt turbo-generator is practically the same as the corresponding 4,500 volt machine, so that this 0.75 per cent loss in the transformer is not compensated for in anyway. If we assume the generator operates 50 per cent of the time and that energy costs 0.4 cent per kw-hr., this auto transformer results in an annual loss of $1,570 which capitalized at 8 per cent represents $20,000.

In regard to the relative desirability of air and iron choke coils:—an air choke coil is appreciably cheaper in first cost, but possesses the disadvantage of a strong external magnetic leakage field which is liable to effect the instruments and to produce mechanical stresses or heating in surrounding objects. It has also been found from experiment that an iron choke coil is less liable in a short circuit to produce the distorted current wave located entirely on one side of the zero line which was above referred to. So that as a result of this it would seem that an iron choke coil, provided there is no saturation at the high current values attained on short circuit, is somewhat more effective in reducing the maximum current on short circuit than would be an air choke coil having the same impedance for steady values.

John J. Frank: In the discussion of the papers by Mr. Merriam and the paper by Mr. Schuchardt and Mr. Schweitzer I will endeavor to confine my remarks to that of the designing engineer, on the current limiting reactance which forms such an important part of both papers.

Neither paper, I believe, intends to convey the impression that every distributing system great or small should be provided with a current limiting reactance as a positive insurance to the elimination of all the troubles experienced by the operating engineer.

Where the impedance of the generator and the transformers is small the introduction of a current limiting reactance will no doubt, relieve the system to a great extent of both mechanical and electrical strains. This is supported not only by the papers presented but by the experience of the Consolidated Gas & Electric Co., of Baltimore, who installed a reactance for the protection of a 5,000-kw., 13,200-volt 25-cycle turbo generator. The particular causes of excessive current are short circuits between the lines, bus bars and generator leads, and grounds on Y connected systems with grounded neutral. The possible effects in mechanical strains upon connected apparatus can best be understood by reference to the strains in a transformer

Take for illustration a 5,000 kw., three-phase transformer, having delta connected primaries supplied with 9,000 volts, 25 cycles. The normal current in the windings is 185 amperes; the measured reactance of the windings is 2.3 per cent. With the secondary windings short-circuited and constant terminal voltage impressed upon the primary windings, the current flowing in the latter would be $\frac{185}{0.023} = 8050$ amperes. The distance between their magnetic centers is 1.7 in. = 4.32 cm.

The mechanical work of the magnetic forces of a circuit in which current is flowing is

$$W = \frac{I^2 L}{2} \tag{1}$$

Where I is the measure of the current and L the inductance of the circuit. This quantity is analogous to the energy of a static charge, $\frac{C\,E^2}{2}$, and to the energy of motion, $\frac{M\,V^2}{2}$.

If F is the force in grams produced between primary and secondary windings, and l the distance between their magnetic centers, the mechanical work done in moving one set of coils through the distance l against the force F would be

$$W = F \times l \text{ g.-cm.} \qquad (2)$$

$$= F \times g \times l \times 10^7 \text{ joules.}$$

Hence, substituting (1) and (2)

$$Fl = \frac{I^2\,L}{2\,g}\,10^7 \text{ g.-cm.} \qquad (3)$$

and

$$*F = \frac{i\,2\,L}{2\,g\,l}\,10^7 \text{ g.} \qquad (4)$$

which is the mechanical force existing between the primary and secondary windings of a transformer at the short-circuit current i.

At short-circuit, the total supply voltage e is consumed by the leakage inductance of the transformer, therefore:

$$e = 2\,\pi\,f\,L\,i \qquad (5)$$

Hence, substituting (5) in (4) gives

$$F = \frac{e\,i\,10^7}{4\,\pi\,f\,g\,l} \text{ g.}$$

$$= \frac{812\,e\,i}{f\,l} \text{ g.} \qquad (6)$$

Inserting the values of e, i, f and l in (6) we have,

$$F = 545 \times 10^6 \text{ g.}$$
$$= 1{,}200{,}000 \text{ lb.}$$
$$= 535 \text{ tons.}$$

This force is exerted between the six faces of the three primary coils and the corresponding faces of the secondary coils; and thus on every coil there is exerted the force

$$\frac{F}{6} = 89 \text{ tons.}$$

This is the average force, which varies between 0 and 178 tons, and thus reaches an enormous value.

If we denote the leakage reactance of a transformer by x, substituting $i = \frac{e}{x}$ in (6) gives as the short circuit force at maintained terminal voltage e, the value

$$F = \frac{e^2 \, 10^7}{4 \pi f g l x} = \frac{f l x}{812 \, e^2} \text{ g.}$$

That is, the short circuit stresses are inversely proportional to the leakage reactance of the transformer. It follows, therefore that on systems of very large powers safety requires the use of high reactance.

In order that a reactance shall protect, its voltage characteristic should be a straight line; that is, it should be proportional to the current flowing. The following empirical formula has been followed in the design of such coils.

The voltage induced in a coil in a magnetic field is

$$E = \frac{4.44 \, \phi f T}{10^8} \tag{7}$$

in which ϕ is the flux enclosed by the conductor, f the frequency in cycles per second, and T the number of turns. The flux produced by a solenoid or coil without an iron core is

$$\phi = \frac{I T d}{K} \tag{8}$$

in which I is the current in the coil, T the number of turns, d the inside diameter, and K an empirical constant which equals

$$K = 0.125 + 0.28 - \frac{L}{D} \tag{8a}$$

where (see Fig. 2) L is the length and D the mean diameter of the solenoid. Substituting (8) in (7)

$$E = \frac{4.44 \, I T^2 d f}{K} \, 10^8 \tag{9}$$

and

$$T = 4750 \sqrt{\frac{K E}{I d f}} \tag{10}$$

The latest expression of the designer is shown in the accompanying illustrations Figs. 1 and 2. The core consists of a cylinder of concrete in which are imbedded anchor plates for clamping bolts.

Radial strips of wood treated to give greatest possible insulation are attached to the core and are provided with grooves into which the conductor is wound. The conductor consists of bare stranded cable and is wound in one continuous piece as shown in the photograph so that eddy currents which might heat the solder or brazed joint in the center of the winding is eliminated. The end turns are given increased space over the average allowance to afford better reliability against electrical or magnetic shocks to which it may be subjected. In addition the conductor on the last turn at each radial support is clamped to further increase the rigidity of the coil. That the reactance operated satisfactorily in the tests made is brought out in the two papers. In order to facilitate cleaning and inspection, the cores and wooden radial supports are given a coat of cream color enamel paint. All of the bolts, nuts, and clamping members are made of brass rather than steel, to eliminate any heating due to the concentration of the flux which would be induced by a magnetic material.

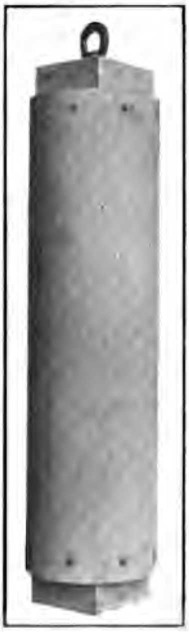

FIG. 1

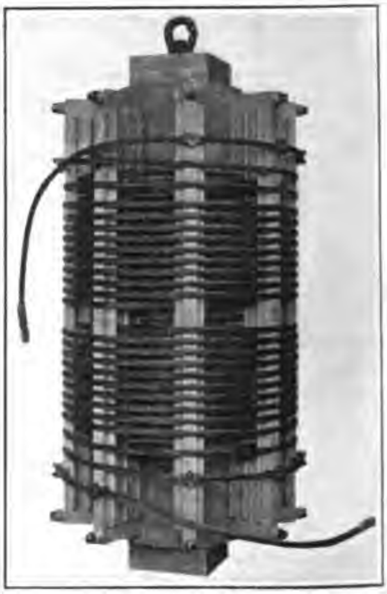

FIG. 2

Louis A. Ferguson: I would like to know whether Mr. Lamme desired to convey the impression that it would be better to use machines of high reactance rather than external reactance? My reason for asking that question is because he made the statement, if I heard him correctly, that by using machines of high reactance you could increase the output, by using a large number of coils per slot.

Our experience here in Chicago has been rather the other way; that is, we have found with our earlier large machines that there was considerable heating, and that the output for the capacity of the machine was limited, and it was necessary, in order to obtain the desired output, to reduce the number of coils per slot, and for this reason, because of the two statements going together, I would like to have him state whether in his opinion it is better to use machines of high reactance, or machines of low reactance, and external reactance connected therewith.

In replying to the question I would suggest that Mr. Lamme confine his remarks to the large machines, such as the 12,000 to 20,000-kw. and leave out of consideration the small machines of say, 1,000 to 2,000 kw.

B. G. Lamme: In machines of large capacity, such as turbo-generators, it is advisable and practicable to obtain large internal reactance by suitable design. If you can increase the number of ampere turns per slot you will tend to increase both the output and the reactance of the machine, and therefore the percentage of current on short circuit will be relatively decreased. In practice it will be found that high reactance machines are generally of relatively high output for given dimensions.

As to the matter of increasing the number of ampere turns per slot, that is a question of design principally. The difficulty with high ampere turns per slot is principally from eddy currents due to local flux conditions in the slot. Very much can be gained on this point by careful design and there is evidence that we can go much further in this regard than we have yet gone.

I think the whole tendency in turbo-generator design is toward the largest number of ampere turns which can be gotten into the armature, without increasing the dimensions, and such increase in ampere turns will also be accompanied by increase in reactance. I am in favor of putting as much reactance as possible into the machine itself up to the limiting amount required, and whenever a sufficient amount for protection cannot be put into the machine itself, then put the remainder outside. I do not favor making the internal reactance as low as possible and putting high reactances outside for I believe that this is a relatively expensive method of procedure.

R. B. Williamson: This paper has demonstrated very clearly the desirability of a certain amount of reactance in connection with large turbo-generators. This reactance may be external as in the present case, or it may be in the machine itself, provided the design is such that a high reactance winding can be used without making a less desirable design in other respects. High reactance in the generator itself means a high specific loading for the stator (*i.e.*, high value of the number of ampere-conductors per slot or per inch of periphery.) In large turbo-generators, most of the heat liberated in the stator copper must pass through the insulation and into the stator iron before it can be carried off, *i.e.*, the cooling effect of the ends of the coils is comparatively slight. In order, therefore, to limit the internal heating of the stator coils, an increase in the number of conductors per slot must be accompanied by other changes in the design, in order to limit this heating. This is particularly true in high voltage generators where the heat has to pass through a considerable thickness of insulation.

Since it is clearly desirable to have a certain amount of reactance in order to avoid the disastrous effects of short circuits on large units, and, since a high reactance involves poor inherent regulation, it follows that close inherent regulation should not be specified for such units. Moreover, it is now general practice to take care of the voltage regulation by means of automatic regulators, so that there is no great necessity for close inherent regulation.

Another point to be considered is that, other things being equal, high speed machines are more likely to be damaged by heavy short circuits than low speed ones. The internal reactance of the high speed generator will usually be less than that of the lower speed machine, but even assuming the same reactance in each case, the coils in a high speed generator span a greater angle, hence the projecting ends of coils are correspondingly longer and more difficult to support securely.

Clarence P. Fowler: In addition to the superior features mentioned, by Dr. Steinmetz, of direct current as compared with alternating current for supplying electrical energy to the congested portions of our larger cities, the following inherent advantages of the former system for this class of service, have been doubtless, in no small measure, responsible for the persistence of this system, (through the use of alternating current-direct current conversion apparatus) to the exclusion of alternating current supply:

a. With direct current available, special devices are unnecessary for charging small storage batteries, such as used in automobiles, etc.

b. As most isolated plants for office buildings, etc., are of the direct current type, the use of direct current distribution at once facilitates, the installation of breakdown service connections for such plants.

c. With alternating current distribution there is considerably more high tension feeder copper required per maximum kw. than with the alternating current-direct current system and as high tension cables cost vastly more per lb. of copper than low tension cables, it is evident that there will be quite a marked saving in this direction in favor of direct current distribution.

d. There is also quite a difference in favor of the maintenance of low-tension cables as compared with high-tension cables and even assuming equal life for each, the scrap value, at the time of removal, would be perhaps 35 per cent to 50 per cent lower for high tension than for low tension cables.

The analogy drawn between the necessity for the use of reactance in connection with our modern high voltage, high-power systems, on the one hand and the resistance of lines, feeders and mains of the older and smaller direct current systems, on the other, is interesting.

The use of reactance, as an adjunct to the operation of synchronous apparatus, as a means of affecting voltage regulation has been fully appreciated, for some time past. In 1905 the writer discussed, the possibilities of the use of reactance, for this purpose, and showed by means of waves, giving the relative phase relations of e.m.f. and current, that the inductive voltage, across a reactance, could be made additive to or subtractive from the delivered line voltage, depending upon the intensity of field charge of the connected synchronous apparatus.

It is, however, only comparatively recently that the power-limiting capabilities of reactances have come to the fore. This, no doubt, has been largely due to the marked movement toward consolidation and concentration, in the central station industry, resulting in unified systems of gigantic proportions, the loads upon which may fluctuate suddenly through a wide range or still worse, short circuits on such high-powered systems may give rise to rushes of current, the volume of which was hitherto unknown, in previous systems. The change that has taken place in the size of central stations will be apparent, when it is noted that the U. S. Department of Commerce and Labor, reports that the average size of central station grew about 72 per cent, in the five year period from 1902 to 1907.

The violent forces acting upon generating transforming and switching equipment resulting from short circuits, on high-powered systems, have, in many instances, manifested themselves in no uncertain way, in the complete destruction of the switching equipment and oftentimes with considerable damage to generating and transforming equipment, in the absence of power-limiting reactances. With the practical elimination of the reciprocating engine from these large stations and the substitution therefor of the steam turbine, a type of apparatus has been introduced the construction of which is peculiarly susceptible to mechanical strains, due to sudden surges of current of large volume. This condition in the turbine, results from the comparatively few poles employed and the consequent relatively greater throw of armature coils, and resulting lack of rigidity of the armature conducting structure. To add to the rigidity of the armature coils, various forms of coil supports, brackets, etc., have been devised, and while this method of construction has greatly aided in preventing distortion of the armature winding, it is evident the method of removing the cause of the trouble through use of properly designed reactances offers one of the most satisfactory solutions of this problem. In fact, one of the largest and most important examples of steam railroad electrification in this country, has found the use of just such reactances a most indispensable aid in the safety and reliability of its power supply apparatus.

P. Junkersfeld: The three papers presented at this session are either based upon or suggested to a large extent by the tests referred to as having been made in the plants of the Commonwealth Edison Company of Chicago. The need for making this long series of tests at considerable risk and expense was brought about by a unique situation. A very large amount of electric power supply business had been obtained and to serve this, there had been installed sixteen (16) large turbo-generators aggregating 204,000 kw. all in a little less than five years. The rapidly increasing responsibility to the consuming public of operating this unusual equipment and the large system of which it forms a part, together with the need of providing additional equipment of still greater capacity and better economy, made it absolutely necessary to make a most thorough experimental investigation and to secure the most positive information on this fundamental feature of reactance in a large system. As a result of these tests the previous tentative plan of installing 6 per cent reactance for each of the remaining thirteen (13) turbo-generators having a frequency of 25-cycles was finally approved and also the plan of installing a limited amount of reactance in each of the two tie lines connecting the Fisk and Quarry Street Stations.

I wish to express appreciation of the careful thought and much extraordinary effort on the part of all the engineers of the manufacturing and operating companies who were in any way connected with these tests, and particularly also to Dr. E. J. Berg and Dr. Chas. P. Steinmetz who gave thereto a very large amount of personal attention.

As a matter of reliability of service, the localization of the effect of breakdowns of whatever nature will probably always be the most important problem. On the one hand there is frequently the temptation to install a still larger amount of protective apparatus which may in itself occasionally cause trouble. On the other hand other methods of securing greater reliability such as independent lines or sources of supply, multiplication of lines, sectionalized operation to a greater or lesser extent, etc., may involve greater expense than is commercially justified.

Referring now to Mr. Lamme's statement, as I understand him, that repeated short circuits do more damage than individual short circuits: In our experience it is the individual short circuit on the high tension system that causes the damage, and which in most cases is so severe that the particular unit or element affected must be repaired or overhauled before it can be again put into service.

At the Annual Convention last year, the discussion of Mr. Cheyney's paper on "Oil Switches" by myself and others indicated a lack of confidence and brought out the fact that very little improvement had been made in oil switches for several years. Tests made during the past year, some of which are included in Mr. Merriam's paper, have indicated the necessity of several improvements in every type and make of oil switches that were tested. They are improvements in oil diverters and baffles, proper reinforcement of various kinds of oil vessels, effect of size of oil vessels, speed of opening, length of break, effect on oil of repeated short circuits and so on. These improvements are in a structural sense of a minor nature, but of much importance in securing more satisfactory and reliable operation of oil switches, and hence I believe we are now justified in placing more confidence in oil switches than before. There is, however, still ample room for further improvements.

It was demonstrated during the Chicago tests that it is not necessary in future that such short circuit tests be made in a large steam turbine driven power house in order to be conclusive as all of the destructive power in such short circuits was found to be due to the stored energy in the generator and none of it to the amount of steam back of the turbine. The tests and investigations described principally in the paper by Messrs. Schuchardt and Schweitzer can, therefore, now be continued in the test rooms of manufacturers as a large generator brought up to speed slowly by a comparatively small motor or prime mover will answer equally as well for further experimentation and at very much less risk and expense.

C. P. Steinmetz: In concluding I wish to say that the oil circuit breaker is one of the most common and most important pieces of apparatus, and at the same time its method of operation is least understood by most engineers, and modifications of it are still continually suggested, based on theoretical considerations, largely erroneous. We must realize that the operation of the oil circuit breaker is not based on any oil circulation, but is based on the control of the explosive forces developed at the break, for extinguishing the arc, and you can easily realize, then, that the concentric gun barrel type of switch has advantages which no other type has as yet been able to approach.

Regarding the induction generator, I have always been very much in favor of it, and I believe it is a very useful machine; and in a central station having an excessive momentary short circuit current, the addition of the induction generator reduces the percentage of short circuit current, since this machine does not add to the short circuit current. But you must realize that you could get the same effect by using generators with lower regulation. Thus, if you consider the station as a whole, there is little difference between a synchronous generator station and an induction generator station, regarding the momentary short circuit current. Every station depends in its excitation on an independent direct current excited field, in one case the synchronous alternator field, in the other case the synchronous motor field, which gives excitation to the induction generator. If you use for the excitation of the induction generator station the converters, synchronous motors, and frequency changers scattered over the system, as these are slow speed machines of low momentary short circuit current, you can materially reduce the short circuit current, but you throw the control of the system away from the generator station into the hundred or more isolated machines, all of which combine in controlling the generating station, and that is not practicable. If you have synchronous motor exciters floating on the system at the induction generator station, economy requires just as high speed machines as our present synchronous turbo-alternator, that is, machines with just as high momentary short circuit current, and you gain practically nothing; and therefore, while the induction generator is a very valuable machine in many instances, the problem of momentary short circuit current is not solved by it. The main field for the induction generator, in my mind, is in the secondary generating stations of hydroelectric systems, as it becomes possible thereby to control voltage, load and frequency of the system from a few main generating systems; the installation control and operation of the smaller induction generator stations becomes greatly simplified, and it becomes feasible to utilize smaller water powers, which could not be economically developed by synchronous machinery.

The last point I wish to bring up is the question of internal reactance as against separate reactance in the generator. That is a question which needs no further discussion, but is ancient history. The development of the generating station has long advanced beyond it. We know we must have power limiting reactance in the individual generator, and it is merely a constructive question—a question of design, whether we put it inside the alternator or outside of it, or whether we make the most economical combination possible, put into the machine as much reactance as possible without sacrificing the quality of the machine, and then put the rest of it outside of the machine.

But even if we had generators with a momentary short circuit current five or six times full load current, that would not solve the question of the operation of the present systems, because if the system is large enough, 100,000, 200,000 or 500,000 kw., you reach a limit where the operation becomes unsafe, even with power limiting generator reactances.

That is where the development has arrived, to put power limiting reactances in the bus-bars. This is really the most essential advance. In the last few years we have come to larger and larger systems, and consequently greater difficulties of operation. Apparatus which was satisfactory in a 50,000-kw. station became unsuited to the operation of a 100,000-kw. station, and apparatus which had been employed in a 100,000-kw. station will become inoperative at 500,000 kw. That was not the case in the old Edison direct current system. There, if you joined generating stations together, there was no material increase of danger, no decrease of safety, because the whole system was limited by the resistance of lines and feeders. Thus the effect of a short circuit was practically the same, whether the station was alone, or other stations were tied to it; that is, there was that feature that the danger did not increase with the increase of the system. That is the most important feature which modern development has arrived at in these alternating current systems, that by breaking up the bus-bars and tie-feeders by reactances, the danger and difficulty of operation, the strain of switches and apparatus, does not increase with any further increase of the system, and the 100,000-kw. system is just as safe or dangerous as the same system will be if extended to 500,000 or 600,000 kw. capacity. That is the great development beyond the power limitation of the generator—the use of power limiting reactances in the bus-bars, which makes an unlimited extension of the system possible without any increase of danger.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, June 27, 1911.

RESPONSIBILITIES OF ELECTRICAL ENGINEERS IN MAKING APPRAISALS

BY H. M. BYLLESBY

In approaching this highly involved subject, I desire to call your attention to the wonderful achievements of our profession. Broadly, our profession is little more than thirty years old. It is true that telegraphy in its various applications and other similar branches had reached a great development at the date I consider as having been that of the birth of the electrical engineering profession in its modern sense. It is also true that the telephone at that time had come into existence as an achieved invention, but it was then purely an invention and lacking in the vast refinements and additions which have made it the huge engine of commerce and intimate feature of our modern life today. In the brief period of from thirty to thirty-four years, the profession of electrical engineering as applied to the generation, the transportation and the utilization of large quantities of electricity has come into existence.

In that brief period the wonderful achievements of electrical engineering, as just defined, have been accomplished. In the broadest sense of the term this development has required the creation of a new art. From the electrical generators of the Commonwealth Edison Company of Chicago, which are this evening furnishing the light and much of the stationary power and the bulk of the power for the movement of the intramural transportation of our great city, with a capacity of 30,000 h.p. per generator, to the generator of 30 or 34 years ago with a capacity of 50 h.p. is a far cry and a long distance.

The electrical transmission systems of thirty years ago comprised at best a few miles for supplying arc lamps and maximum distances of about a mile used in the infant industry of lighting by incandescent lamps. To-day, transmission lines of over 200 miles are not uncommon.

At the birth of our profession probably the largest steam engine did not exceed an indicated capacity of 2,000 to 2,500 h.p. and engines of that capacity were extremely rare and confined almost exclusively to slow moving pumping operations. To-day we have reciprocating engines driving electrical generators of 10,000 h.p. capacity and steam turbines driving electrical generators of 30,000 h.p. Probably these sizes will be exceeded in the not distant future. I am calling your attention to this wonderful development; this creating of a new art and the attendant collateral developments of the subsidiary machinery and materials required, for the purpose of emphasizing the points which I wish to discuss very seriously. Among other achievements, directly or indirectly, of our profession has been the great development of the water wheel. It is probable that thirty years ago there was no water wheel in existence which developed substantially more than 500 h.p. To-day water wheels are in operation developing upwards of 15,000 h.p. for the purpose of driving electrical generating machinery.

Along with the achievements of our profession and taking its inspiration therefrom, and being forced thereto by our demands, has been a contemporaneous development of machine shop practice and machine tools. To-day there is a condition of accuracy, a necessity of working to microscopic measurements and a machine shop practice which did not exist before we required it and which I believe would not have existed today excepting to fulfill our exacting needs.

Likewise the foundry of today is producing steel and iron and bronze castings in quality, in size and in accuracy—all forced upon them by the advances of the electrical engineers' profession. The entire practice of hydraulic engineering, if not revolutionized, has been thrown forward by leaps and bounds by the requirements of the electrical engineers in the useful development of water powers for the purpose of generating electricity.

Along with this has gone the scientific and painstaking study of rainfall, of runoff, of careful detail investigation of natural precipitation through rain and snow fall, the action of ice in its various forms, the action of melting snow and the control, as far as humanly possible and on a wider scale than ever dreamed of in the past, of the Titanic forces of nature in swollen streams, floods and cloudbursts. Storing water in reservoirs for the purpose of utilizing the stored or flood water at low water periods of the stream and the development of the reservoir on a scale heretofore unheard of have all been ancillary to the brains, the genius, the achievement of the men of our profession. The development of electric engineering has been a continued series of advances, step by step and leap by leap. There has been more obsolescence and more retirement of electrical machinery and tools and devices far in advance of their natural life, due to the continuing improvement, than has taken place in the history of or the development of any other art. The duties of the electrical engineer have been more eclectic, and I believe more exacting than those of any other profession.

A famous man of the world is said to have remarked during the most glorious period of the administration of the elder Pitt that "one had to look into the Gazette each morning to keep pace with the victories won." In our profession one has to read the daily press and carefully study the columns of the technical press to at all keep pace with the new developments, the new achievements and the new victories of the profession from which we all make our livelihoods. This tremendous growth from the dynamo of 50 h.p. to the generator of 30,000 h.p.; from the incandescent lamp as a luxurious curiosity to the incandescent lamp which is as much a feature of our modern civilization as our running water; from the transmission distances of a mile or two to transmission distances of 200 miles; from the electric motor existing as a laboratory toy to the electrical motor of universal use and of 10,000 to 15,000 h.p. has taken place within the span of years conventionally covered by the term a "generation." It has been achieved within the lifetime of most of the members present and it has occurred since the young manhood of many of us.

This is in truth a wonderful accomplishment. All who have contributed to it can justly take pride in the fact. It is probable the annals of civilization do not contain a parallel, but along with this proper pride, with the feeling of well merited satisfaction, let us not forget that collaterally and a part of it, something without which it could not have taken place, has been the work of the promoter and the banker. No new industry can be established, or when established can continue, and no art can grow to the dimensions of ours without the continued presence of the individual who supplies the capital, the money, the financial resource to the inventor and the engineer. Large and continuing supplies of capital are required for research, for producing inventions, for the carrying out of the inventions and the development through their period of incipiency, of temporary failures and disappointments.

It is probable that thirty-four years ago there was not to exceed $1,000,000 invested in every feature and part of this art, and today, taking the entire civilized world, and in the absence of statistics, I believe that several billions of dollars would be short of the amount of capital invested in manufacturing plants, in generating stations, distribution systems, water powers, trolley roads, motors and subsidiary details employed in the business which has been produced by electrical engineers and the promoter and capitalist working hand in hand and together during approximately a generation.

I think we should seriously consider this fact; that we should give to the promoter, to the capitalist, to the man who is able to influence capital and to place it at the disposal of the men of our profession, the credit that is properly due him. The achievement of the electrical engineer would not have been possible if it had not been for the presence of the man with money who believed in the commercial possibilities of our art as from time to time developed and who produced the capital with which to continue the development of that art. I am entirely confident, although it is a matter purely of conjecture and not susceptible of direct proof, that inventions as great as any which have revolutionized the world have died, have never been heard from because the much abused capitalist was not on hand to stand behind the inventor during his period of discouragement and disaster. I believe many other worthy inventions and developments have attracted no great notice, have not accomplished their destiny because of the absence of the man or corporation with both faith in the invention and the means of producing the capital to develop it.

Our profession has indeed been fortunate in having had associted with it from its inception men who were sufficiently intelligent, courageous and far-sighted to see the merit of the inventions and developments which from time to time were produced and who had withal the faith and the ability to continue to stand behind these inventions and developments with their capital during that period which we all know has taken place, when these inventions and these developments were under criticism, temporary failure and while only disappointing results were being reached. During this period of disappointment, of hazard, during this period of modifications from the original plans and disappointments and changes, the man or corporation with money was present to tide the infant invention or industry over the shoals and hazards which surrounded it, and except for the presence of men of the type of which I am speaking, with their courage, their faith, and their capital, many of the inventions and developments of our profession would have been in the grave of permanently disappointed hopes and non-fulfillment.

Today our art is developed. The product of the brains of the electrical engineer are so well known, their commercial utility is so thoroughly established, particularly in the principal lines of our achievements as to lead us to be forgetful perhaps of that period which the older ones of us recollect so clearly. This period, due partly to the crudity of our own devices and the undeveloped condition of our own inventions, due partly to the unstable condition of the collateral features upon which we depended such as steam engines, boilers, water wheels and manufactured articles, was a period attended with heart-breaking anxieties not only to the inventor and engineer, but do not forget that it was also a period of heart-breaking anxieties and disappointments to the man who had invested his capital in those things.

As I look back over the sweep of 30 to 34 years and from the standpoint of maturity which comes with middle age, and long experience, it is a continuing marvel to me that in spite of the perpetual disappointments and the hazards pertaining to this business, capital was found to proceed with the development of the art, and in all fairness as I look back over this period, the admiration I feel for the inventor and the engineer, the pride I take in their achievements is, in my own mind, shared with the courage and faith and enterprise of the men of capital who stood by us and our operations during those trying times.

Today there is a world of discussion regarding the value of a franchise, the terms of a franchise, the privileges it affords, the obligations it carries and the fraud which in the minds of the public is supposed always to be inseparably connected with anything bearing that name. There is much comment, nearly always unfavorable, regarding the conditions under which franchises for electric light, trolley roads and power transmission companies have been issued. If those who, probably with the best intentions possible, are criticising these matters had gone through the experience of the earlier days, they would change their opinions. In the full blaze of the glorious noon in which we now find ourselves in our profession it may be difficult but it should not be impossible, to turn our gaze backward to the early struggling days of this art, and I believe that by doing so, a more just view of the situation will result.

In those days franchises were given freely. Any one who applied for a franchise would receive it and, as a rule, without burdensome restrictions. The community which was favored by having capital build for its service an electric light plant to furnish what they believed to be a luxury and which otherwise they would not have had, or a community which was favored by a company who in return for a franchise would spend the money necessary to change the cruel and totally inadequate intramural animal transportation of that town or city to an electric transportation system was properly and deservedly welcome. The only feeling on the part of the citizens of that community or the governing body issuing that franchise was one of thankfulness that the electric light or trolley line was to be given them and one of pity for the individual or corporation who was so foolish as to invest capital in such hazardous enterprises. The same remarks apply to the development of water power. These streams were not fully developed. Some were developed for mills, but generally for usage only during the daytime and far below the capacity of the stream.

Until recently the laws governing the ownership of the power in the stream were believed to be pretty fairly understood along the lines handed down from our Anglo-Saxon ancestors. The company or individual who came into the community and produced the capital to develop these streams was royally welcome and he was viewed generally with some wonderment regarding his financial obliquity, as in the case of the individual or corporation building the electric light plant or the trolley road. If a brief and unprejudiced study is made of the history of these earlier electric light, trolley and water power companies, it will be impossible to depart from the conviction that the persistence and courage of the promoter and capitalist who carried them through their earlier periods of disaster and lack of credit is quite as notable an achievement as that of the inventors and engineers who produced the physical and scientific part of these enterprises.

This enterprise and this courage which heretofore has been wisely fostered by the commonwealth has given the United States of America the most universally extended, the best operated public utility plants in the world. In the vast majority of cases the service rendered by the corporations is furnished to the public—with superior service with its wide extensions—at less cost than in any other country. Various contributing causes have produced this result. Among these causes has been the natural inherent courage and enterprise of the American. In addition to this, however, have been the liberal franchise grants issued in the past and the freedom from onerous restrictions both for occupancy of streets and the purchase and development of water powers. A broad and liberal construction which has justified the issuance of stock which would eventually pay to the projectors and developers of these enterprises when they became successful something in addition and beyond a mere fair interest return on their investment has also had a profound influence upon giving to our country the best utility corporations of the world. Without these features this development with its low charge to the public could not have taken place. Due to these features it has taken place.

Throughout the older settled sections of our country scarcely a hamlet is without electricity for lighting and power and large sections of our farming and ranching lands are equally supplied. Due to the liberal policies in the past which allowed a reward to recompense the hazards and the courage when such hazard and courage had passed its period of financial loss, we have as a result in this country steam railroads, telegraph lines, telephone lines and gas service which in excellence of service, the extent of the service, and the price charged for such service are not equalled in the world. These broad and fair policies in the past have justified the public service corporations in extending their operations, properly expecting as a result of employing additional capital and as a compensation for the risks incurred in pledging their credit and the credit of the individuals behind these corporations, to receive an accruing profit when their enterprise and courage had been justified by results, the companies uniformly lowering from time to time the charge made for their service. No fault was found with the increasing returns upon the capital invested for the purposes and under the circumstances set forth, if at the same time the rates for service, which were already fair as compared with any other country, were being lowered.

In this way communities throughout our country are today served with public utility commodities at an actual loss to the companies serving them. These communities pay no more for the commodity of the public service corporation than the thickly settled communities, the companies operating this service having been heretofore justified in providing the capital and extending their plants into non-productive fields, standing the immediate loss resulting from this policy in consideration of an ultimate profit when their brains and energy and courage had been justified (if it was justified) by the upbuilding of these communities and the properly resulting profits then accruing. Bear in mind, as previously stated, that in the entire history of public service corporations in this country there has been heretofore a continuous lowering of the price charged for the commodity or service rendered to the public with the sole exception of the trolley roads, which started with a price to the public for service rendered which could not possibly be lowered and it is believed in many cases cannot be continued.

Abuses have taken place in the past on the part of the corporations, on the part of the public served by the corporations and on the part of the legislative and law administering bodies. At the present time my opinion is that both the public and corporation are reaching a common meeting ground, requiring public service corporations to be protected and regulated monopolies; these corporations to be governed as to their rates and to be protected from competition by so-called " public service commissions." With this doctrine as such, the public service engineer and operator has no quarrel. We do file a plea, however, that these public service commissions be composed of men of character, men of ability, men who have accomplished something in the world; that these commissions be composed of men who while fair and upright are conversant with the business which, under the laws governing their action, they are controlling.

The abuses which have undoubtedly taken place in the dealings between the municipal bodies and the public service corporations have been as distasteful to the corporations as to the public, and the cry of the corporations is for a fair hearing, for an intelligent hearing, for fair recognition of the benefits they have conferred and a demand to be relieved from the hardships and frauds which in many cases they have suffered at the hands of politicians a partially educated public sentiment and the municipal governing bodies. It is believed that properly constituted public service commissions, appointed for " good behavior," composed of high-class men, suitably paid and operating under broad and liberal laws, will accomplish this much-to-be-desired object.

Granted, as I believe it must be, that the foregoing is a candid statement of the situation, the public should recognize that the so-called public service corporations should be encouraged and fostered instead of being strangled and discouraged. The widest latitude should be afforded the operations of public service corporations under monopoly and protection, and fair laws administered by conservative and able public service commissions.

Coming now specifically to the subject of my paper, the electrical engineer must recognize that in addition to the multiplicity of duties he has been called upon to discharge, he is now confronted with a new class of responsibilities from which he cannot shrink. To these responsibilities he must give the best that is in him of experience, of fair mindedness, of wisdom and of justice. In the world at large and particularly in the United States we appear to be in the midst of a period of flux and change.

Old methods and old standards are passing away; new methods and new standards are demanded. With the marvelous progress of the civilized world since the last great economic and social changes, it will be a shame if the present crisis fails of a solution more rational and with less hardship and destruction than has attended previous solutions of economic and social crises. Out of the present controversies we must endeavor manfully and fairly to bring a condition of justice to all concerned and in our share of duty in these matters we must make every effort to be intelligent and not to be found wanting in fair dealing and honesty between man and man, between corporations and the public and between governing bodies and corporations. Principal among these new responsibilities which are being rapidly thrust upon our profession is making appraisals to determine the value of the property of a public service corporation.

These values, in accordance with the unmistakable present trend of the times, are to be made a basis upon which or from which are fixed the maximum rates which these corporations are to be allowed to charge for service rendered. There is much discussion taking place on replacement values, reproduction values, depreciation values, and intangible values. In the majority of cases the property to be appraised represents a continuing growth or a construction period from its inception. Much of the construction work we are called upon to value is concealed from view, such as foundations of buildings, foundations for machinery, submerged protions of hydraulic construction, conduit systems and gas pipes. In every case the structures or plants have been built in what is conventionally termed a " piecemeal " fashion. Almost every public service corporation has started from a small beginning and added to its plant continuously, and the finished structure today represents construction work which has been continued from the time the original property was created. In meeting the questions which the spirit of the times is demanding answers to, very properly a demand is made by all parties to the controversy that absolute and entire frankness and complete candor pervade the negotiations. Properly a period has been put to the practice of dissimulation and trickery and misrepresentation on the part of the public, the governing body, and the corporation. From a long experience I can state for my part that trickery and dissimulation and unfair dealing in the past have been fully as great on the part of the public and the governing bodies, if not greater, than on the part of the corporations. Following this proper demand for candor, I desire to call the attention of my fellow members of the American Institute of Electrical Engineers to the painful fact that it is extremely rare for a professional engineer or constructor in any branch of industry, in any branch of construction, to estimate the cost of such construction with accuracy and that the practically uniform experience has been that all such estimates have proved woefully less than the cost of the completed project.

I believe we should be candid and frank on the subject. Every one of us whose duties require him either as a principal or in an auxiliary capacity to be responsible for the furnishing of capital to build any given public service construction or to develop any given enterprise, knows full well from a long and painful experience that unless he provides for indefinite excess charges or leaves some other avenue of escape, the enterprise or construction when finished will be burdened with a floating debt which seldom is of small relative proportion. This debt is the difference between the estimated cost of building the undertaking and the actual cost as developed after the event. I believe there has not been a considerable piece of public service construction in recent years where the finished cost complete has not overrun the estimated cost by a minimum in a few cases of 10 per cent to 15 per cent to a maximum in a majority of cases of a dangerously large percentage which not infrequently has gone to an excess cost of 100 per cent. All experienced contractors will bear out the statement I have made. The comparatively few contractors who finish their career with more money than they started with, or with more money than they themselves started with and without leaving their banks or guarantee companies in the lurch have an experience of profit and loss, the loss on one job the profit on another. These men have learned their lesson and today they will only with the greatest reluctance take a contract which, under an enforceable bond, compels them to fully complete any large given piece of work for a given sum of money. Where they are forced to take any part of their contract in this manner they very properly, I think, provide for extras at a given rate, expecting that their loss on the lump work will be made up by the profit from the extras. This is too thoroughly understood to admit of any discussion.

I shall not attempt to go into detail of this well-nigh universal experience of underestimating. A large total excess cost of a completed undertaking may be represented by a small overrun in the cost of the purely physical construction and an omission of large material collateral expenditures which are part and parcel of the completed project. The shortage may be due in this view of the case to an ignorance on the part of the individual furnishing the budget to be provided; ignorance which results in overlooking a material and proper part of the cost of the completed project because it was not strictly physical construction. The overrun resulting in the floating debt therefore, in many cases, may be quite largely made up of the omission of those necessary costs which in the discussions of the times are termed "intangible values." But no matter in what direction the shortage occurs, no matter whether on the strictly physical part of the construction or from forgetfulness or ignorance of the proper costs under the head of intangible values, the facts remain substantially as I have stated in my premise.

How careful, therefore, how fair minded and liberal should be the point of view of the professional engineer in appraising the value of another man's or another corporation's property for the solemn and serious purpose of having based upon his appraisal the return which that man or that corporation is to be allowed to receive upon his investment. It is unfair that an engineer or appraiser who recognizes at the bar of his own conscience that his own estimates have been uniformly overrun should make his appraisals without taking into consideration and manfully applying to his estimate his own factor of individual inaccuracy, his own personal factor of nearly unfailing underestimating.

If the profits to be allowed public service companies were to be on a broad and liberal basis this feature would be of less importance. The spirit of the times, brought around partly by mistakes, by selfishness, by unfairness, on the part of all parties to the contract, the tendency of the times, actuated to a degree by certain irresponsible magazine writers, magazines and papers, and by certain politicians, all tend to reduce the return of the public service corporation to a low point. At best it would indicate, allowing the public service corporation after paying its operating expenses and depreciation charges, a distributable sum equivalent to from 7 per cent to a possible 10 per cent upon its reproduction value, the higher percentage being rather hoped for than indicated. It becomes plainly evident, therefore, how grievous a hardship may be worked upon corporations if the appraisal of their property is as much below the real value of their property as the average estimate of the engineer has proven in the past. I think the situation is one of the most momentous which confronts our profession today. A large part, I presume 90 per cent, of the activities of our profession have resulted from the continuing growth and existence and development of public service corporations. If these corporations through under appraisals or drastic regulations are discouraged and cease their active aggressive growth of the past it will be immediately reflected in the lessening demands made for the services of the members of our profession.

Capital is a peculiarly mobile commodity. Capital will flow from one part of the world to another in accordance with the inducements which are offered it. Capital will leave any given field with great speed if it finds that it is receiving an unfair or unjust recompense or other fields offer greater inducements. Without capital, modern enterprise is impossible. The most beneficial use of capital is to have it employed in developing new enterprises, extending existing enterprises which in turn develop and add to the wealth of the communities served. In our extending enterprises we afford profitable employment for increasing population and we ameliorate the conditions of human existence. The profession in which the members of this association are engaged could not exist at all if capital withdrew its support from enterprises depending upon the genius and ability and conscientious effort of the electrical engineer.

I urge upon all of you to carefully consider this subject, to avoid the influence of the idea that the professional engineer can get along without the services of capital. Capital on its part must treat the public, the laboring man and the professional man with fairness and liberality, with more fairness and liberality than it has in the past. On the other hand, the professional man who from the nature of his calling and its dignity carries a large influence in the community in which he operates must not forget the close co-relation between brains, labor and capital, and neither through professional indifference or professional jealousy allow himself to give capital an unfair hearing or an unjust decision.

We must avoid the fallacy that only the physical portion of a corporation's property is entitled to a value, a fallacy which has led many engineers, many business men and many corporations to disaster. The facts being that beyond the naked physical value there is required a very large and material sum to change that naked inert mass of physical construction into a live, progressive earning entity. The omission of the cost of making a going concern in addition to its naked physical value has been the root and cause, in my judgment, of a large proportion of the disasters which have overtaken enterprises in the field in which we operate.

These remarks and more to the same effect apply to the question of intangible values and when called upon to deal with these matters I hope the fullest consideration will be given to them. These intangible values generally embrace interest during construction, accidents and insurance during construction, engineering charges, supervision charges, and they should include proportionately, the tremendously large sums expended by public service corporations in developing the business, in educating the public, and producing a sale of their commodity, whose reflex effect in subsequent reduction of the operating charges should be considered as proper cost in the value of the property. Further proper charges, of an absolutely legitimate nature, to the intangible value account include the legal expenses of organization and of putting the enterprise on its feet, the discounts on securities sold or brokerage paid for finding of the capital and particularly in the case of the older companies, the large sums spent in absolute good faith in what was really a period of experimenting to obtain the best apparatus, the best systems, and methods adapted to the requirements of the company happening to be in question. Due regard should always be given to the added cost of piecemeal construction which has been an unfailing incident of all of these corporations. In all fairness it should include the losses due to obsolescence and the discarding of workable machinery long before its life had been exhausted, this discarding being for the purpose of keeping pace with the times and in the last analysis for the better serving of the public.

There is a tendency, I hope a diminishing tendency, to be unfair to public service corporations and to be entirely oblivious of the hazards and risks they have incurred in the building of their business and to be forgetful of the profound importance and great benefit they have been to the communities they serve.

A recent example and a very pertinent one of this tendency to be unfair has occurred in the appraisal of the value of one of the largest utilities in a large western city. The appraisal was for the purpose of determining the proper reproduction or replacement value of this utility. The formula was rather clearly understood as pertained to the physical property, deductions were to be made and were made for the accrued depreciation, allowances were made for what had evidently been unusually expensive piecemeal construction and matters of that description, the theory being that as regarded the physical value of this property, its appraised value would represent what it would cost to reproduce the property in its present condition.

In general this formula was carried out fairly until it was found that a material part of the distributing system of this company was now under paved streets, but that due to the enterprise or necessity of the company in the past a part of its underground system had been placed in the streets in question before they were paved; that is, the paving above this underground system on a material portion of the company's property had taken place after its distribution system was in the ground. The ruling of the body making this appraisal was that this company was not entitled as a part of its value to the cost it would have been put to of placing this distribution system under the paved streets and the difficulty of sustaining this ruling is plainly evident from the fact that wherever this company has put its distributing system underneath paved streets or where it is doing it today, the cost of that paving has applied to this company and is allowed as a part of the value of its plant. It would be hard to conceive of a more direct effort to discourage enterprise than this particular ruling. If the company had waited to put all of its distributing system under the paved streets until the paving was down and had then ripped it up and buried its distributing system it would have been allowed the cost of taking up and replacing the paving. Because it did it in advance it was not allowed that cost. This particular city is far better off from the course which that company pursued because its pavement over that particular portion of the distributing system was not injured by being taken up to put the distributing system underneath it.

We all believe we are approaching a far better understanding between all parties concerned on these questions than has existed in the past. The effort of all of us must be by conscientious effort, by candor and sincerity to bring around this better condition. However, with the tendency of the governing bodies to make decisions such as I have just referred to, how extremely important it becomes for the engineer entrusted with the making of an appraisal to be sure that he has not underestimated, to be sure that so far as his intelligence and authority go he gives to the property under consideration the benefit of all the value he believes it is entitled to, both physical and intangible.

In closing I desire to urge upon all of you a sense of the responsibilities now being thrust upon us; to urge upon you a sense of the dignity of our calling, and to express the hope that with the unusual opportunities possessed by the members of this organization for forming a basis for a proper measure of the questions of values; that we approach these subjects with high intelligence, with a profound sense of the responsibilities resting upon us and with appreciation of the fact that in the combination of capital, the public and professional engineers, no hardship can be worked to any one of the three without inevitably producing its full quota of disaster to the others.

I say all of us, many of us, by the manufacturing corporations or the public utility corporations—in creating the electrical enterprises; some of them not electrical, because we are not all electrical here, but most of us were engaged in creating the electrical enterprises some of which have come up for public criticism since that time. We all went ahead at that time on the theory that the franchises were valuable, and therefore they would stand capitalization, and they were capitalized. Consequently, the public was required to pay a return upon not only the real cost of the property, but also on a fictitious cost, or an assumed cost, or an assumed value, rather, instead of cost, on these franchises. Now, taking into consideration the pioneer period during which these enterprises were created, it is not perhaps unfair to say that these corporations were entitled to an excessive profit upon the actual physical value of the properties of that day, and that, therefore, they were justified in assuming that the franchise had value, and in paying a rate of return upon these franchise values—I do not know that I will say franchise values, but partly upon franchise values and partly upon capitalization that it was necessary to put into the properties to replace the parts of the property that became obsolete during the rapid changes in the state of the art, thus introducing into the capitalization of the companies not only the question of franchise values, but also the question of obsolescence.

My position on that matter for the past three years, after having had five years to think about the subject and come to conclusions that I thought satisfied my own conscience is—that a public service corporation is justly entitled to have more than a fair return upon the actual money put in under such conditions, namely, pioneer times—that a company is entitled to excessive profits for those times, or if it should not make these excessive profits, it is entitled to live long enough to make a good profit not only during those times but also during its life, so that the people who put the money into the enterprises under great stress and great risk, shall make more than ordinary returns upon their money, for having taken the risk of the venture, provided that when the company has earned and paid to the stockholders this profit, all excess over a fair return upon the value of the property thus performing the service shall be put into a fund to gradually amortize obsolescence and other values previously carried in capital account but representing no real property. I have recently put this plan into practice in one the of largest cities in this country—and got the corporation, also one of the largest, to agree to it. The fundamental principle underlying that theory is this: That the public should pay, for instance, to a street railway corporation, the actual cost of producing the service which is given to the public, plus a fair return upon the actual capital necessary to create the property, and also that necessary to continue its operation. In the case of early railroads or railroads created under pioneer conditions I would give them much more than the present rate of interest; and in cases where the properties have operated at a loss during the earlier periods, I would allow the companies to maintain in their capitalization the actual cost of the properties plus these early losses, and I would allow them to continue to earn a higher rate of interest than what is now usually considered a reasonable rate on money, until they have earned back out of the property these early losses, and a liberal return upon the actual money they put into the property, which would cover not only the present physical value, but also the cost of such machinery and material as has become obsolete during the creation and operation of the property up to the present day.

This is upon the assumption that from now on the company is going to be regulated as to its rate of return by public service commissions or by other state or municipal authorities, and thus be prevented from earning excessive returns out of which to recoup their early losses—because the corporations when they went into these enterprises assumed they were going to be able to operate them long enough to get their money back, and make something more than an ordinary rate of return otherwise the parties furnishing the money would never have gone into the enterprises and operated them at a loss during the early periods. Now, the public may state its proposition in two ways—*i.e.*, it may say we will allow you to make large returns up to the present, but from now on we are going to regulate your rates, so that your return will be only the ordinary interest on your present investment. I believe that if the public is going to regulate from now on, it should see that the past losses of the companies are taken care of and that the capital that went into the enterprise in the past should yield a liberal rate of interest up to date, and if the company has been honestly managed and has not earned that interest and also enough to make up its early losses and return the capital represented by obsolescence, that this capital should stay in the capitalization until the company earns it out, and from that time on the company should accept what is considered now a reasonable rate of return upon the actual value of the property then providing the service and also that from that time on, all earnings over and above that rate of return should be put into an amortization fund, to gradually retire this capitalization represented by obsolete property, purchased during early operation, and other development expenses. I hope I made myself clear upon that point, because I believe it is fundamentally right that the public should pay the cost, plus a fair return, to the company that produces this service. It is right, when the company has earned back its money which it took to produce that service, that the public should pay a return simply upon the actual value of the property which is producing the service, assuming that the people who went into the project in the earlier days have made a good, liberal return on the investment.

Therefore, our present methods, or rather the methods of some of us who are engaged in endeavoring to straighten out some of the present difficulties, are as follows: We assume that these corporations have been organized under the above conditions, and have operated up to the present time, some of them with great success, and some with indifferent success. Those which have been operated with indifferent success are entitled to the consideration which I have mentioned, but those which have operated with great success, however, and have taken out of the property a good liberal rate of return, are not allowed to carry in capitalization this excessive capitalization any longer. In other words, if the records of the property show the property has been honestly and well managed and the rate of return, taking gross receipts, and deducting operating expenses, have not been enough to pay a good rate of return on the investment, the amount spent for obsolescence and for early losses should be kept in the capitalization, but if the records show that the company has made a liberal return on its investment and that the extra money has been declared in excessive dividends instead of creating a depreciation fund out of which to rehabilitate the property, then I say such a corporation has no right to claim the benefits of the plan just suggested, and it should be judged on the physical value of the property as it exists today.

That is the method which was applied to the valuation of the Chicago properties some five years ago, namely, that these properties, especially one of them, had earned excessive rates of interest for years, some of them as high as 35 per cent upon the money they cost, and consequently the people who owned the property received back many times over the money they put into them, and consequently there was no hardship when they had to accept a depreciated value of the property, namely, a value which represented the real property in existence, with the understanding that from now on, when the property has been rehabilitated and firmly established in such a manner that the securities of the properties are absolutely reliable, as the pioneer days are gone, the people who now put money into or have money remaining in these properties should be willing to accept a reasonable return from this time on, be that five, six, seven or ten per cent, whatever you agree upon—but it cannot be 25 per cent or 40 per cent, or something like that, because the money now invested in the properties, is invested in a stable investment, and we must accept it as such and the public utility corporations should recognize that those of them who have accepted this view of the situation are the ones who are getting along most successfully in our municipalities today.

On the question of values, in making a valuation of the physical property, of a public service corporation it is right, in my opinion, to determine, first, the cost to reproduce the property new, and in that cost to reproduce new must be considered not only the actual value of the physical property that you can go out and find, but you must consider also interest during construction, engineering expenses (usually five per cent) legal expenses applicable to construction only—I do not mean attorney's fees incurred in the creation of the company, or the securing of franchises, or anything of that kind but only those applicable to construction work alone and a reasonable contractors' profit.

When fixing the rate a corporation should be allowed to charge for service there are sometimes other expenses which should be included in its development expense, such as preliminary technical expenses, legal expenses during the formation of company not connected with construction expense, cost of consolidations and reorganizations, sometimes a reasonable promotor's profit, supersession of equipment due to the rapid advance of the art, reconstruction due to unforeseen contingencies, brokerage, discount or premiums on securities, and sometimes franchise and " going " values, including losses during early operation, all of which should, however, eventually be amortized and eliminated from the value of the property upon which the public should be expected to pay a rate of return, although it is but fair that the company should have time to earn this amortization fund.

These are what are known as development expenses, usually running anywhere from 10 to 25 per cent of the cost to reproduce the physical property new. Some companies will contend and say it should be as high as 35 per cent. I never yet found a property where I thought such a percentage should be allowed, but have found some where 25 per cent was fair, some as low as 12 to 15 per cent, some 22 per cent, and I think that from 20 to 25 per cent is not ordinarily an unfair figure to add an order to determine the actual cost of reproducing new the physical property.

My time is short, and I have endeavored in a general way to outline my judgment regarding the subject of Mr. Byllesby's paper, which is a very valuable discussion of the general subject.

In regard to Mr. Floy's paper, he makes the point that the engineer must know for what purpose the valuation is being made, and states that so far as the value of the property to the owning and operating company is concerned, that is, for its use, a very low rate of depreciation should be considered. I am not so sure that that is correct. I maintain and always have, when you are considering a question of rate making, that the company asking for the rate, should be allowed a rate based upon the cost to reproduce the property new, taking into consideration the development expenses which I have mentioned, and that a condition precedent to that valuation, requires the property to be in first-class condition so as to be able to give first class service and if the property is found to be in bad physical condition, that the company has no right to ask that the rate be based on the cost to reproduce new, unless the company has in its treasury, or has somewhere a depreciation reserve fund, such as we have in Chicago, provided of course it has been able to earn such a fund sufficient to put the property in first-class condition, so as to give a first-class service, which is what you require of it, and which is the condition you require it to be kept up to in order to entitle it to the rate you gave it.

Many communities will attempt to fix a rate upon the depreciated value of the property. I think that is a short sighted policy from the standpoint of the public, because if the rate is fixed on that value the company has no chance to raise enough capital to put its property in first-class condition, to give first-class service, and consequently the rate should be based upon the capitalization to reproduce the property new, or on the present depreciated value of the property, plus enough to put it in first-class condition, and that money must be in the treasury of the company, or in a fund for that purpose.

W. F. Wells: Mr. Floy has covered the subject of depreciation in such a broad and comprehensive manner that he leaves almost nothing to be said. However, I would like to voice my approval of the statement he makes, to the effect that in estimating the value of the property, only absolute depreciation be considered, and not any theoretical value of depreciation. I think that property which is in good order, and operating efficiently should not be depreciated when rate cases are under consideration. In other words, any company which is maintaining its property in first-class condition, so that its original utility is unimpaired, should not be compelled to depreciate the value of that property for the sake of rate making.

As to Mr. Byllesby's paper, I have heard one or two engineers take exception to the manner in which he has treated the question of replacement value of underground subways over which new pavements have been laid. A company is entitled to this increment value just as much as it is to the increment value of real estate or any other property. Companies frequently install subways in advance of new pavement in sections of cities where for years to come the gross revenue will not pay the fixed charges, but they do this on the idea that the difference between the original cost and the replacement value after the new pavement is laid will in part offset these carrying charges, such as interest and taxes during the time of nonuse.

Regarding the general subject of appraisal work, one of the most difficult and laborious features is to obtain physical inventory of the underground system of an electric light company.

I had occasion this spring to make a complete inventory of the underground property of the Brooklyn Edison Company, and the method followed may be of interest to some here.

The property was all recorded graphically on maps and records, contained in some twenty large volumes. On each page of these books were shown the details of the sub-surface structures in about 500 lineal feet of street, including the subways, man-holes, cables, Edison tubes, junction boxes, etc. The problem was to tabulate and summarize the amount of each type of construction.

I determined that the Hollerith system, such as was used by the United States Government in tabulating and summarizing the statistics of census reports could be made the most satisfactory. We had all the necessary perforating, sorting, and automatic calculating machines, which were in use for analyzing our output and revenue, and after thorough analysis of our underground system, I found that by slight modification, it was possible to adopt these machines for making the inventory. The data on the record books was transcribed to special forms which were prepared, using one sheet for each page. In order that these data may be perforated on the templet cards, for the sorting and adding, it was necessary to indicate all descriptions in figures or key numbers. Every street in the city was given an arbitrary number, which, with the sheet number, completely indexed the sheets.

All types and characters of subway construction were indicated by nine figures, the first two indicating the number of ducts in the bank; the third, the material, such as tile, fibre or iron pipe; the fourth, the number of ducts wide in the trench. Two more figures showed the distance from the top of the duct bank to the top of the street pavement, the character of which was indicated by another figure. Two more showed the date of installation, thus; 16.5.4.06.1.07 indicated 16 ducts of tile laid four wide, and therefore four deep with six feet of cover between the ducts and top of an asphalt pavement during the year 1907.

For man-holes two digits showed the perimeter of the hole; the third indicated the character of cast iron head employed; two more the depth of the hole; another the material, whether brick or concrete; another the type of paving and two more the year installed.

For cables the first digit indicates the character of insulation; the second the number of conductors; the third the voltage; two more the size of conductors, and two more the year installed, thus: 4.3.2.2.5.07 indicates a lead covered paper insulated cable having three conductors for use on 6,600 volt service, each conductor being 250,000 cm. and installed in the year 1907. All quantities were naturally expressed directly in figures. After the record sheets were prepared, of which there were 3,800, some 33,000 cards were perforated, the operators being able to punch from 200 to 400 per hour.

These cards were of two kinds, one showing number and character of services, quantity and style of subway and duct feet occupied, the other showing the number and type of manholes, and length of various cables installed.

These cards are then placed in the sorting machine, which may be set to select any type of construction, after which the adding machine summarizes the quantities.

These cards and record sheets, with additions and withdrawals, now form a perpetual inventory of our underground property and are so indexed that any card may be checked at any time.

John W. Lieb, Jr.: I think that the Institute is to be congratulated for having had presented to it these two papers which are somewhat afield from the usual line of papers which have been presented before the Institute heretofore. We all of us, whether engaged in the railroad field, or the transportation field, or the electric lighting field, must sooner or later come face to face with these problems, and it is of the utmost value and importance that we shall have a fairly general view and grasp of the situation. If this is not the case, when we come to represent our respective interests before public bodies, such as public service commissions, or regulating state or municipal bodies, we will find it necessary to make our views known, perhaps inadequately, perhaps incompletely, through the medium of our attorneys.

Now, all of us who have had experience in trying to deal through our sister profession with technical matters must recognize the extreme difficulty and the unsatisfactory method of having to deal through a representing medium commonly unfamiliar with the technical expressions and the technical requirements of these cases. Therefore, I say that these gentlemen have done a real service to the Institute in calling the attention of the members to these questions, so that they shall become well informed and have presented to them in a compendious and complete presentation the gist of these matters, and Mr. Floy in his paper has presented what is a fairly complete list of definitions which certainly should prove extremely useful.

Unfortunately, in presenting matters on a subject of depreciation rates of depreciation are given in tables. It is very easy to apply them in a way to make them misleading. These rates of depreciation are usually based on the exhibition of the physical life of the properties of the apparatus, without taking into consideration the necessity of a very much shorter career, due to supercession, conditions of obsolescence, etc., and it is unfortunate that tables of depreciation do not specify that they do not cover obsolescence and do not cover any supersessionary reducing time limit. If you will refer to the table given in Mr. Floy's paper, and what follows, you will see how evident this is. Under arc lamp, for instance, the fourth item, rate of depreciation in per cent per year for arc lamps is six per cent. Now, we all of us who have been engaged in this business know how thoroughly inadequate any such allowance as that would be with these rapid changes that are going on in this field. The same thing would apply, for instance, to the rate of six per cent, or 6.5 per cent for electric meters.

Now, we have had the assistance in furthering this rapid voyage from the operating room to the scrap pile of very many of the members of this Institute, and they are partly responsible for this continuous cycle of improvement. It is, of course, to this continued cycle of improvement that we owe the immense expansion which this industry has had, but it also should be recognized that this continued cycle of journeys, of rapid journeys, from the operating condition to the scrap heap, should have its proper expression in what is the real and proper rate of depreciation, and if tables of depreciation do not include supercession or obsolescence they should so specifically state.

I was very much interested, indeed, to hear Mr. Arnold's statement of his views in regard to a matter of the very utmost importance to all public utility corporations, that is to make a reasonable and proper provision for disappearing assets, the physical assets which in the course of these consolidations and mergers that have already taken place, have disappeared, and it is a most unfortunate condition, for which our present financial conditions and lack of explanation is largely due, that the public is misinformed, and considers that these disappeared assets are denominated by some of our friends as " water ".

Now, gentlemen, in bringing these vast properties together, and in order to give the public the advantages which they have received in large measure by bettered service or lowered rates, it has been necessary to scrap enormous quantities, enormous parts of the apparatus that have been functioning in some of these smaller corporations, which have been merged or consolidated into the larger institutions. Now, for this apparatus that has so soon gone out of use, and for which the larger corporation had no use whatsoever, securities were issued in good faith and bought by the investor, and yet the physical assets, as has been referred to, have disappeared, and when these valuations are made even the closest scrutiny and search will not find anything in the existing operating system that represents these disappeared values.

Now, I think that Mr. Arnold has, as a result of the deep thought which he has given to this subject, and of his experience, touched upon a very important and reasonable method of suggesting they take care of these assets which have disappeared, which cannot any longer be represented as inventory values, in the case of physical valuations of these properties.

It is most important that, as our President has stated in his opening address, which, I believe, should appeal to every engineer, that this is a field in which the engineer should rise to opportunities of wider usefulness. It is astonishing that public opinion should be moulded and shaped on these most important and vital questions relating to our industry by people who have not had the right experience of the business and who have not had information as to these repeated cycles of changes which are reflected in our business conditions, and it is up to us, as engineers, to do our part to shape and mould public opinion, so that not only the public shall have its fair, equitable and just treatment and consideration, but that the public service corporations also shall receive on their part that fair treatment which the public, when it is once correctly informed, will not be slow in awarding to them.

Schuyler S. Wheeler: I have only two points to make.

First: It is evident that depreciation of the property of public service corporations is the important part of the subject as presented, but the titles of the papers are not limited to this. This difficulty would be met if the titles of the papers were conc sidered as amended to read, " Depreciation as Related to *Publi-Service* Electrical Properties," and " The Responsibilities of Electrical Engineers in Making Appraisals of *Public Service* Corporations."

Second: It seems to me it would be much better if all kinds of depreciations of physical property were unified and classified, and a single rate of depreciation was universally adopted for each kind of article making up a property. I refer to the several ways in which depreciation is figured at present as illustrated under " Classes of Depreciation " in Mr. Floy's paper. I think he calls for both " absolute " and " theoretical " depreciation. These various rates of depreciation for the same thing, are intended to cover different circumstances, for example, the fact that on one hand a piece of apparatus may become very old and yet be wholly and fully useful to the owner, and, on the other hand if the apparatus is to be disposed of the value is very small.

Now I think that there is approximately a definite value for each piece of apparatus at different periods in its life; that such value includes actual wearing out and obsolescence and all of the other factors, and I think if we could arrive at some definite way to include all of these factors, and at a rate for each different kind of property, the problem would be very much simplified for us and many arguments would be cut out. I think it proper that in the conduct of every kind of business an amount should be charged each year against the earnings, representing that year's share of the reduction of the value of the property, and whether it be in a lighting company, a street railway, a manufacturing plant, or anything else, such charge should be deducted each year. If the property is considered each year as reduced by that amount the problem becomes quite definite and very much simplified.

E. Leonarz: Mr. Arnold called attention to the fact that a fair interest is allowed. Now, we certainly don't fear that rates would be increased, due to the original rates being too low. We have never heard that rates are being adjusted, when extensions of lines outside of cities have been asked for, but we hear that such rates are being lowered, or that lines are being extended from the previous limits, and the result is simply a higher investment, and sometimes that companies are going to the wall. Who is going to pay for these extensions and betterments? I think that such companies should be allowed increased rates, and that public service commissions should also take into consideration that only a part, and only a very small part, of the capital invested has received what we can call a fair return.

Public service commissions are also apt to take exception to the high rate of interest allowed to certain companies, which from the start, were led to believe that the field which they started in would really be better than it proved to be.

A. H. Ford: The question of reasonable return having been mentioned the speaker raises the question as to whether it is good policy for the controlling body to fix a single rate as a reasonable rate of return. He would answer in the negative; for if the management of a property knows that charges can be increased if this rate of return on the value of the property is not reached and will be reduced by the controlling body if it is exceeded, the incentive for operating the property more efficiently or with greater enterprise, is removed.

A better plan, it seems to the speaker, would be to fix the reasonable rate of return between certain limits as, for example, five and fifteen per cent of the value of the property; giving the controlling body the right to order a reduction of the charges only in case the rate of return is greater than the upper limit and allowing the management to increase charges only in case the rate of return is less than the lower limit.

Specifically; under the present plan there would be no incentive to replace an obsolete piece of machinery which involves a high operating cost by a new machine which would reduce the operating cost and thus allow greater earnings, which would be an invitation to begin action for a reduction of charges; while under the proposed plan this would be advisable. In another instance a reduction of charges might cause such an increase in the business that the earnings would increase but the management would hesitate to reduce charges if it knew that any increase in the rate of return resulting therefrom would be the cause of a further reduction until the rate of return was at the old figure. That this is not a hypothetical case is shown by the action of the Wisconsin Railroad Commission reported in the *Electrical World*, Vol. 57, p. 1599, in the case of the Madison Gas & Electric. Co.

Geo. L. Hoxie: Mr. Floy's paper is a timely one, upon an important subject. It is likely there will be little dissent from most of his conclusions. The table giving the rates of depreciation that have been adopted by various official bodies is particularly valuable, and the quoted extracts from various Court decisions are convenient for reference.

Certain features of the paper however, are likely to develop sharp differences of opinion. I would take exception to the notion of " absolute " and " theoretical " depreciation, and to the idea that " theoretical " depreciation must be provided for only as a part of operating expense, while " absolute " depreciation, for which Mr. Floy indicates quite a different value, is to be used as the basis on which rates are to be fixed, capitalization allowed, etc.

It does not seem that such a division of depreciation into two values, one to be used in one case, and one in another, is at all possible as a practical matter and if it were tried I believe that it would quickly lead to an intolerable situation. In a rate fixing matter for example, the Board, or Commission, fixing the rates would, under Mr. Floy's theory, assign a value to the physical property based upon what he terms " absolute " depreciation, which it seems would usually be very close to the first cost of the apparatus considered, (as in the case covered by the St. Louis decision, so approvingly quoted.) Then the Commission would fix a yearly *rate* of depreciation, and this rate of depreciation would perhaps be more *per annum*, charged to operating expenses, than the *total* " absolute " depreciation.

After rate regulation had gone on for a few years, say 10 years, we should have a fund, paid out of operating expenses, equal to perhaps 50 per cent of the first cost of the plant, and this fund, as would ordinarily be the case, has perhaps been largely expended in extensions and improvements to the plant, (to the extent of keeping its " theoretical " total value constant); but the property of the Company, based on " absolute " depreciation would, if maintained at full operating efficiency still be figured at within a few per cent of its original cost or would be, on this theory, (with a " theoretical " rate of say 5 per cent, nearly 50 per cent more than the first cost of the original plant, at the time when rate regulation started. Yet all of the excess value upon which rates must then be based, has been contributed by the consumer. The consumer has thus paid for the privilege of paying dividends to others on his own payments to them. One can see readily enough that this theory carried out over a term of years would mean rates so high that any Public Service Company should be able constantly to increase its physical property, without any additional capital investment, meanwhile paying full dividends each year on the increased value for that year.

Of course, something of the sort is what has actually gone on in the case of many successful Public Service corporations; but it is precisely such a state of affairs that has brought about rate regulation. Some important Public Service enterprises have mainly been built out of excess earnings. Once built and the excess earnings capitalized, it is impossible for the public to go back, and in effect take away property from stockholders, on a plea that it was paid for by the public out of excess earnings.

If now, we base plant value on one rate of depreciation of plant, and allow operating expenses on a rate of depreciation that is many times higher, we have made no improvement by our rate regulation. On the contrary we have made matters worse, for, under rate regulation, we have eliminated the competition that formerly limited rates, and we have in effect guaranteed rates sufficient to pay dividends on unjust values. The thing cuts both ways. You cannot charge depreciation in your operating expenses unless you lower your estimated plant value by the amount charged to operation for depreciation, less the amount put back into the plant. The total "lessening of worth" of a plant during ten years is the sum of the depreciations for each of the ten years—of course less any money put back into plant. In my opinion, with a new company, starting under rate regulation, and having rates permitting fair payment to capital and the charging of straight line depreciation to operation, the value of the physical plant must, each year, be reduced by precisely the amount of the depreciation fund remaining unexpended at the end of that year. The Company must also be allowed to call any unexpended balance, capital, and to earn dividends upon it, crediting earnings of course with any income the fund may have produced.

As a practical matter the depreciation fund of any large company cannot be made up of a lot of separate accounts each balancing the "lessening of worth" of some one item, but it should be a fund balancing the total lessening of worth of all items together. Also as a practical matter, the depreciation fund would not be held in cash for any great length of time, but should be invested, so as to produce a revenue. Of course the investment may be in any form of property, perhaps in the bonds of other companies, or perhaps in the bonds of the company itself. But the most usual form of investment will doubtless be in *new plant construction*. Such investment should yield the greatest possible return, and should provide in the best possible manner for balancing the depreciation of the previously existing plant. If an exactly correct rate of depreciation be determined and so balanced by a fund, used in extraordinary repairs, extensions, new constructions, etc., the physical value of the plant will remain constant (unless new capital be also used in construction).

Since no human measurement can be absolutely exact, care should be taken to see that the rate of depreciation chosen is a little too high rather than a little too low, otherwise the company will in time be wrecked. With a depreciation fund a little too large constantly being put into improvements, the value of the property will constantly appreciate. But the public, in the form of a commission, may very justly step in at this point and prevent any increased capitalization or earnings on account of such increased value; but may say to the Company, "This increased value is not yours, but belongs to the public, since it exists solely because we, in our care not to wrong you, purposely allowed you to collect somewhat too large a depreciation fund."

It is easy to see that under such a financial scheme as here outlined, a corporation's bond and stockholders would become more secure each year as to the safety of their original investments, yet they are not allowed any "unearned increment." There would probably come a time when not merely 75 per cent or 80 per cent but perhaps as much as 100 per cent of any additional funds needed for extensions, could be had from low rate bond issues. The public, on the other hand, would get the benefit of steadily decreasing rates.

A much more difficult situation, and perhaps such a one as Mr. Floy had mainly in mind and attempted to meet by two rates of depreciation, is found where a public service company having handled its business as it pleased for many years, suddenly comes under rate regulation. Such cases are almost the usual ones now. It must be admitted at once that fixed rules are almost impossible. Each separate case is of a corporation whose history is somewhat different from every other one. Some corporations have been conservative, some reckless; some have had good engineering, and some no engineering; some have maintained depreciation funds, some have largely built their properties out of excess earnings, and some have capitalized everything, watered to the limit, made no proper provision for depreciation, and perhaps the promoters have withdrawn with personal fortunes, leaving a lot of deluded stockholders, a run down plant, and a new rate making commission, to be dealt with.

About the only general rule that can be laid down is that each case must be treated with common sense at the start, and that the treatment must look toward the establishment. as quickly as possible, of such conditions of business management as would be enforced at once on a new concern.

There can be no doubt that a " theoretical " rate of depreciation must in every case be charged against operating expenses. Possibly, to begin with, the theory of a lesser " absolute " rate of depreciation might bring out a common sense result in some cases, and *for a limited time*. In my opinion however, there is no case, and there can be no case, where the continued use of two separate rates of depreciation, applied to the same property, over a considerable series of years, will not bring disaster.

The real difficulty in making an appraisal of machinery in use, lies in what is almost the impossibility of correctly estimating the remaining period of life of the machinery, during which it will be of effective service to its original owners. This is a different matter from estimating the useful life of the machinery alone. Many a machine sold second hand, for approximately scrap value, has a long period of useful life ahead. But for its original owners the machine's life ended when it was discarded.

An engineer making an appraisal must not therefore limit himself solely to the physical condition of each machine. The physical condition of property may be the smallest factor of its value. In some way or other, the appraisal must be made to include a deliberate judgment of *value of useful service remaining*, in that situation, or to that company, plus salvage value. To say that an engineer can make such a prediction accurately for any given machine is to say that he can predict not only future advances in the art, but how many years ahead those advances will come. The best that the engineer—or anyone else— can do, is to judge the future by the past. He may say that various classes of machinery have in the past had such and such periods of life. He may increase those periods by an amount that in his judgment it is fair to allow, assuming that future progress will be less rapid owing to greater standardization. He may then apply a depreciation based on age, and years of service remaining, and while method and result may be criticized, both are likely to be more nearly right than any other yet suggested.

Objection comes mostly from a general sense that injustice may be done to innocent stockholders, where application of straight line depreciation would make a drastic reduction in capital, of a sudden, which could not have been anticipated. In such cases the public must share responsibility for not having regulated matters earlier and a commission may reasonably, for a time, allow capital, and earnings, on some sum in excess of actual value as depreciated, and may thereby in effect assess upon the public some part of the loss due to bad financial history, which loss the public and the aforesaid innocent stockholders then share, upon some basis to be determined by the commission.

Conflicting Decisions. The Master's Report in the Consolidated Gas Case, from which Mr. Floy quotes, seems at first to be opposed to the method of estimating depreciation just outlined. As the Master's opinion was sustained by the Supreme Court, it seems a little presumptuous to differ—yet other decisions do not indicate that approval of the Master's Report constitutes a final pronouncement concerning the method that we must follow. The Master approves an estimate " based on a detailed examination of the property as it stands to-day." No one could object to such an estimate if correctly made. Such an estimate would necessarily consider not merely physical condition, but probable length of future service; and it is evident from the Master's opinion that he actually did consider the plant in condition to give service over a long period to come. It must also be noted that while a straight line depreciation is well within the possible limits of accuracy for any case where the length of life is short, in cases where the estimated life is long, as in the Consolidated Gas Case, a moderate rate of interest for the fund makes the annual charge against operating expenses very small. A sum amounting to a few per cent of the first cost, set at interest at the end of half the estimated life might in many cases reproduce the property at the end of its theoretical life. It does not seem possible to get more than a meaningless figure from a computation based on a life of 100 years or more. In Mr. Floy's curves, Plate 1, the annual charge to cover depreciation, at 5 per cent on 100 years of life, is practically nothing. The fund and interest, accumulating even at the end of 10 years, can hardly be read on the curve. In fact any estimated life beyond 60 to 75 years might reasonably be called perpetual life, for no computation, based upon such a life will be within the limits of error introduced by other uncertain factors, not the least of which is the estimated life itself. It seems clear therefore that the opinion in the Consolidated Gas Case by no means tells us not to figure straight line depreciation in the case of an electric lighting or railway plant, having a probable life of less than 20 years. Certainly it does not tell us to figure two kinds of depreciation, one to use for an operating charge, and the other for a capital charge.

Curves of Depreciation. In Fig. 1 of Mr. Floy's paper are given six curves, as illustrating ways in which depreciation actually takes place. Curves 1 and 2, are based on selling values, assuming that the depreciated property is sold for use elsewhere. As the author says, depreciation of a going property should never be figured on the basis of these curves—unless the property depreciated is of less value to the seller than to the buyer, and in that case the property should be considered as scrap, and not included at all in a value of the property on which for instance, rates are to be based. Curves 1 and 2 therefore are not truly such depreciation curves as may be used for going properties. Curve 6 is for property which it is assumed will be kept at close to 100 per cent of operating efficiency until just before the end of its life. It seems that the reasoning given in connection with curve 6, while at first sight plausible, is in fact wholly misleading. Assume, as shown by this curve, that a property gives precisely the same service at the end of the 17th year of its life as at the end of its first year. Also assume, as the curve also assumes, that at the end of its 20th year it has only scrap value. Decided the " fair value " of the property is very different at the end of one year and at the end of 17 years. The property value is due to its ***remaining capacity*** to serve—not at all to the ***momentary character*** of its service. Curve 6 cannot even approximately illustrate possible true depreciation. The curve is not really a depreciation curve at all, but is in fact a curve whose ordinates represent operating efficiency, at the end of any given time—quite a different thing.

Curves 3, 4 and 5 are the only curves of Fig. 1 that may fairly be called depreciation curves for an operating property. Mr. Floy calls these, curves of " theoretical " depreciation. It would seem better to call them curves of " actual " or " real " depreciation. The only uncertain point is the length of life. Give the real length of life of the property, and curves 3, 4 and 5 are not at all " theoretical ", but very practical and definite.

Interest on Depreciation Fund. Curve No. 4, and the similar curves of Plate 1, show the effect of interest rates, assuming that the gradually growing depreciation fund is kept at compound interest until the life of the property is over, and is then exactly sufficient to replace the property. Curve 3 illustrates what is usually called " straight line depreciation."

There is something to be said on both sides of the question of whether to include interest computations, or to use straight line values. Personally I much prefer the straight line method for all ordinary cases of property having a life not over about 25 years, the objections to including interest figures being:

1. It is not practical, or desirable, to have an actual fund against each piece of property, maintained as an invested fund during the property's life.

2. If the fund be general, against the entire physical property, it will be drawn from, at varying times, and usually invested in plant extensions, none of them specifically replacing any especial part of the old plant, but all together maintaining the total physical property at a constant value.

3. It is difficult, and perhaps impossible, to estimate in advance the probable life of property so closely, that the error will not usually be greater than the difference between straight line, and curved line, depreciation. (For very long lived properties this might not be true.)

4. Rates of interest will not be constant during the life of a property, and will depend largely on whether the fund is kept in bank, used in purchase of bonds, or re-invested in extensions. One method may result in a rate of interest twice as great as another.

5. The straight line method is far simpler.

Even where statistics are so accurate as those of human life, it is found that progress in sanitation, medicine and surgery, together with the strict examinations of the physical condition and family history of applicants, has resulted in an average length of life of insured persons, appreciably greater than indicated by the tables.

It would seem impossible to estimate the average useful life of 1000 similar dynamos with such accuracy as to justify the inclusion of interest. For one thing there may be quite a difference of opinion as to when a dynamo is really "dead". Furthermore the salvage value at the end of the period of life cannot be estimated at the beginning of life. There are other similar uncertainties none of which occur in the problems of a life insurance actuary.

It seems therefore that such account as it may be desirable to take of interest on fund, at least for the depreciation of electrical machinery, might usually best be considered as a lengthening of the life period; using always "straight line" depreciation.

Fifty Per Cent Method. The "fifty per cent method" in certain cases, such as those mentioned by Mr. Floy, is quite a satisfactory one. It implies a relatively short life, or the inclusion of an interest factor. It should be noted that there is nothing theoretical about the depreciation where the fifty per cent method is applicable. Take the case of the incandescent lamps, on customers premises, of a company furnishing free lamp renewals. Some lamps are new, some just ready to be exchanged, and others of all ages between maximum and minimum. No one would maintain that the total value of stock, old and new together, is not close to 50 per cent of the new value. Also it is evident that the renewal of lamps as they become burned out or blackened keeps the whole outstanding stock at about a constant value, making no special additional charge for depreciation necessary, except as lamps may become cheaper due to improvements in manufacture, etc., or as new types may make the old ones less valuable.

The question of when the " fifty per cent method " should be used is one requiring careful judgment. It is interesting to observe that when the Third Avenue Receiver, as Mr. Floy tells us, refuses to provide for depreciation, on the plea that the property has so many elements that all deterioration is simply wear and tear, and to be charged as maintenance, he really applies the " Fifty per cent method " to his entire system, and in effect inventories his property then and there at 50 per cent of its replacement value. If he is correct in his notion as to maintenance, the system may be easily appraised.

Use of Terms. The suggestions made by Mr. Floy on the subject of a more general agreement on terms are very wise. It would seem appropriate for the Institute, through some of its committees, to take up the whole question of terminology in connection with depreciation, and assign very definite meanings to the commonly used terms, and perhaps to coin new words if desirable. Such a committee might well work in connection with committees from the other societies, as all are equally interested.

P. H. Thomas: Mr. Floy has given us a valuable paper on the subject of depreciation and has clearly brought out a number of matters which are at present the subject of wide controversy. There seems to be an endless line of opinions and theories as to what constitutes the logical basis for the disposal of many of the questions arising in assigning depreciation rates in actual cases and more broadly in the matter of the determination of rates and utility investment values. Such matters are good will, promotion expenses, cost of building up a business, insurance, engineering, etc.

Is it not clear, however, as a matter of public welfare, and common sense that there is but one sound and logical rule by which all such questions must be judged, namely, whether under the ruling proposed the capital invested will receive a sufficient return to warrant its leaving other available lines of investment for public utility plants, this being the sort of property now under discussion. The community must have its utility plants developed and extended continually, and while it is under no obligation to contribute in any degree for the benefit of the capitalist, it must make its offer attractive enough to secure takers. It may be and in fact is possible to force a company which is already involved in a particular plant to do things it is inequitable to require and even to make some extensions to save a portion of the investment already made, which cannot be withdrawn, but this policy would in the long run end in stopping all development and furthermore is obnoxious to our sense of justice.

From this point of view it is relatively easy to determine the disposal of many of the disputed questions. Would the particular expenses sought to be added to capital account be necessarily incurred were the plant to be reëstablished ***under the original conditions***? The costs of preliminary studies, within reasonable limits, the costs of engineering, insurance, the cost of building up the business, the losses and inadequate profits during the early years, interest charges, and all such expenses are necessary steps in the establishment of such a plant and are a legitimate part of the investment. On the other hand, the cost of mistakes, bad judgment, discounts or profits which are paid to persons or corporations for some reasons other than the necessity of the plant itself would not be legitimate additions to the capitalization. This exception should, however, be noted that a suitable percentage added to actual cost due to mistakes or accidents, etc., should be allowed to the extent actually found in similar undertakings carried out with average good judgment. Promotion expenses should usually be small in public utilities as such systems usually grow from a small size with the development of the community.

On the basis here set forth the cost to reproduce new is not a fair measure of the value of the plant. It should be the cost to reproduce again under exactly the same conditions that existed when the plant was actually developed. But in practice on account of the great difficulty of fairly determining such a cost under the old conditions it is customary to determine the cost new as a guide. Many appraisers in relying mainly on the cost to reproduce new seem to consider that the records and books of the company are so confused and interlaced with legitimate and illegal expenditures that it is hopeless to try to sort them out. This is a dangerous precedent from the point of view of securing fresh capital and suggests the importance of keeping the books so that legitimate expenses can all be shown, with their justification, at a later period, and with enough detail so that suspicion cannot be thrown on the totals.

There is another aspect of these discussions which has not been very clearly stated. In most cases of the determining of depreciation or in rate making, we may either strive to determine what the precedents of the courts state to be the law, leading to the probable immediate holding in any given case, or we may consider what is the ideal or logical or wise or fair determination. While in one sense the precedents of the courts are fixed rules, it is nevertheless true that the decisions must ultimately meet the sense of public fairness and good policy, either through additional legislation or otherwise and that the continual discussion of the ideal, that it may be clear and well recognized, is of the greatest importance to the community. It is gratifying to note that the spirit of intelligent fairness seems to be rapidly spreading, in spite of certain somewhat radical tendencies that appear.

Wm. A. Del Mar: In the summary of his paper, Mr. Floy gives first place to the following feature.

" The necessity of a more general agreement on and uniform use of the terms used in considering and discussing the subject of depreciation, by the engineering profession."

Mr. Floy is to be commended for pressing the importance of this point, for in most of the literature on the subject of depreciation the meaning of the principal terms has to be painfully ascertained from the context. Unfortunately our author, while generously assisting others over the pitfalls of loose phraseology, himself falls into them, dragging the reader into the very trap that he set out to save them from. For example, he defines the word depreciation in two different ways. The first definition is as follows.

" Webster defines ' depreciation ' as the act or state of lessening the worth of and in this sense it will be used by the writer. . .".

The second definition which occurs only twenty lines after the first says that " depreciation has been used to mean—

" The annual amount expressed, as a percentage or in dollars that should be laid aside to renew or replace the article in question at the time of its abandonment, plus the annual expense of maintenance of repair expended in removing such part of depreciation as is practicable and good economy. This then includes all classes of ' lessening of worth ' and is the application of the term preferred by the writer. . . .".

The first definition says that depreciation is the state of something and the second, that it is an amount that may be expressed in dollars. If both are to be accepted it must follow that " states of something " can be measured in dollars, a point of view that opens up a new era in political economy and the theory of dimensions! I fear, however, that science is not destined to be enriched by such a discovery, as many readers will notice that the second definition is invalidated and rendered useless by the fact that it defines depreciation in terms of itself.

Later in the paper, wear and tear, decrepitude, supersession and obsolescence are defined as classes of depreciation. It is obvious that our author here follows his first definition, but with the result that he tries to measure supersession and obsolescence in dollars, which is impossible because the physical dimensions of these two quantities are indeterminate while that of a dollar, as explained below, is determinate and known. If Mr. Floy had defined depreciation as a lessening of value and then said that supersession, obsolescence, etc., were *causes* (not classes), of depreciation he would have kept out of this confusion.

If carelessness occurs in the definition of depreciation, what shall be said of the following use of the word valuable?

" On the other hand, apparatus that is in use and rendering a service economically, may for the purpose for which it was intended, be as valuable as when originally installed, although its age may be approaching the limit of its life."

Is it possible that our author does not distinguish between

" useful " and " valuable ", that he uses the latter term to mean the former? Apparently not, for it is obvious from what follows that the confusion is one of ideas and not merely of words. Thus, curves 1, 2 and 6, he says, " may be taken to represent absolute depreciation " by which he means *loss of utility*, while curves 3, 4, and 5 represent " theoretical depreciation " by which he means *loss of value*. The fallacy of Fig. 1 is the attempt to measure utility in dollars which are obviously incapable of measuring anything but value.

Another example of the confusion of the terms value and utility occurs under " Service Value."

" Physical property, honestly and intelligently purchased with a view to its suitableness for the service intended, aside from some hidden defect or untoward accident maintains its original value practically throughout its life, etc."

Does Mr. Floy mean value where he says value, or does he mean utility? This is only one case out of a score, where the meaning is doubtful, and the same criticism applies to many other words.

Leaving the field of corrective criticism and entering that of constructive thought, let us consider a few definitions which are not open to the objections cited above.

The *value* of a commodity or service is the inverse ratio of the amount of that service or commodity, to the amount of another service or commodity which it can be exchanged for. Value is therefore a ratio and according to modern political economists, is proportional to the ratio of two numbers, one of which is the ratio between the demand and supply of a service or commodity at a given place and time, and the other the ratio between the demand and supply of another service or commodity at the same place and time.* Expressed mathematically it is as follows:

$$\text{Value} \propto \frac{\frac{D}{S}}{\frac{d}{s}}$$

where D and d represent demand and S and s represent supply. The physical dimensions of value are therefore undeniably those of a ratio or number.

The magnitude of the ratio appears when an exchange is effected, or proposed and therefore to all intents and purposes is nonexistent without an actual or potential exchange.

Just as an angle is measured by the ratio of its magnitude to the entire circle, so a value is measured by the ratio of its magnitude to the entire sum of exchanges effected in some arbitrary time, say a year. The equation of value and money is as follows:

$$A = D\ V$$

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*Science of Money, Alex. Del Mar.

where A = value of the sum of all the exchanges effected with money, per annum.

D = number of dollars in circulation.

V = number of times per annum that each dollar is used, usually called the velocity of circulation

Expressed in terms of their ultimate physical dimensions

A is a value, which is a number, divided by a time or $\left[\frac{1}{T}\right]$

D is a number represented by $[1]$

V is a number divided by a time, or $\left[\frac{1}{T}\right]$

Hence our equation checks by dimensions $\left[\frac{1}{T}\right]=\left[1\times\frac{1}{T}\right]$

The time element may be eliminated from the equation by dividing each side by T. Performing this elimination we obtain $a=D\,v$, where v is the number of times each dollar is used while exchanges to the value of a dollars are effected with money. Hence an exchange which involves $1/n$ of the total value of all exchanges will require $1/n$th of $D\,v$, which therefore is the measure of value involved in that exchange. The physical dimensions of $D\,v$ are the same as those of D, that is to say a number. All this is very simple, but the number of people who write on depreciation and don't know it, is legion.

Value being a number and its unit also a number, the physical dimensions of *money* are those of a number, and do not involve time, mass or length. Hence money cannot measure anything that involves time, mass or length. Now utility is not a ratio or number; it is a complex quantity incapable of mathematical expression and having no unit. A gold nugget might have been useful to Robinson Crusoe, but its value in dollars on Crusoe's island was certainly zero. Utility not being reducible to the physical dimensions of money it is as futile to try to measure utility in dollars as to measure distance in pound weights. Yet by disguising loss of utility under the name of " absolute depreciation " Mr. Floy attempts to perform this impossible feat. By substituting " percentage of original utility " for the word " dollars," in his Fig. 1 our author would have made his meaning clear without using absurd expressions, although an attempt to measure utility or any other quantity having no unit is apparently vain.

This excursion in to the realm of elementary monetary science seems necessary because depreciation relates to a change in value expressed in money and this change cannot be clearly understood without a clear conception of what it is that changes.

Another element in the conception of depreciation, is *deterioration*, which may be defined as any change in a property due to wear and tear or the ravages of the elements, which tends to impair either its usefulness or its life. Akin to deterioration, is *loss of useful association*, which may be defined as any change in the associations of a property, which tends to impair its usefulness or life. Finally before coming to depreciation itself, it is necessary to define *obsolescence* as loss of commercial utility in any property, due either to the advent of superior substitutes or to its own inadequacy to meet new conditions.

Depreciation may be defined as a lessening of value due to deterioration, loss of useful association or obsolescence.

Deterioration can be approximately predetermined from the results of experience, while loss of useful association and obsolescence are of a more speculative character and less amenable to computation. While, therefore, it is possible to estimate to some degree of accuracy, how much it will cost to overcome deterioration, it is possible only to bet or insure against obsolescence and loss of useful association.

The expression *replacement cost* means the cost of replacing an existing property by a new one either identical with it or possessing equal utility.

On account of deterioration, it is necessary to make replacements and repairs. Those replacements and repairs which occur frequently, or which severally cost a small portion of the whole replacement cost, should be made when required, paid for out of the annual earnings and charged to direct operating expenses. Such charges are called *maintenance* charges.

Replacements which occur infrequently and which cost an important proportion of the whole replacement cost, cannot be paid for out of the annual earnings without causing exaggerated operating charges in given years, unless a proper sum is set aside each year to provide in advance for the impending replacements. Such a sum is called a *depreciation charge* and the accumulated fund made up of these annual sums and the interest thereon, if invested, is called a *depreciation fund*. Considering only those elements of a property whose depreciation is offset by a depreciation fund, we may state as a general principle, that the ideal condition is that the depreciated value plus the depreciation fund should at all times be equal to the replacement cost.

This completes a set of definitions which are proposed in place of the corresponding ones used in the paper under discussion.

Mr. Floy's paper contains a great deal that is valuable upon this important subject and it is to be regretted that the presentation of such an elaborate research should be disappointing in the very feature that its author apparently set out to perfect, namely the uniform and correct use of the terms used in the discussion of depreciation.

F. W. Harris: Mr. Floy says that by the second plan consumer saves 25 per cent. I do not think this is so broadly considered and I cannot see that the consumer saves anything with prevailing interest rates considered. What happens is that each year the corporation borrows an additional $100,000 and charges the interest to the consumer. This is fair to the consumer and if the rate of interest is a fair one is financially equal to paying it. This is readily seen if the consumers are considered as each year putting aside $100,000 at 6 per cent and each year paying the interest therefrom plus $60,000 to the corporation. At the end of 50 years the consumers will have a sinking fund of $5,000,000 and the corporation will have a debt of $5,000,000.

While, however, such a course as outlined in the first plan is fair to the consumer and practically equivalent to the second plan it is suicidal to the corporation due to the difficulty of properly securing this loaned depreciation. The corporation is in reality loaning its customers $100,000 a year without security. Such a course would be the height of folly but there are many corporations today which are on a smaller scale persisting in just such a course.

Mr. Floy's paper is aimed at such and is to be commended but his statement regarding consumer's position does not seem to me sound and as this is an important subject I have ventured to comment as above.

Horatio A. Foster: Mr. Floy has covered quite fully in his paper about all the ground work of the subject but I wish to add to his definition of the word depreciation the following: theoretically, depreciation of an object is that deterioration in its value that cannot be made good by repairs nor can it be made good in any way except by full replacement or renewal. From a bookkeeping standpoint we must get away from the ordinary conception of depreciation that it is just wear and tear because in making the changes on the books the wear and tear and what is termed deferred maintenance are all chargeable in operating expenses. In evaluating a property, however, all these conditions of wear and tear and deferred maintenance are considered with the depreciation the definition of which thus becomes, *any lessening of worth at the moment of appraisal.*

With the possibility of repeating I will try to add somewhat to the discussion. Every piece of physical property begins to wear out or deteriorate the minute it is started in operation. To be sure in many cases this is very slow, in very many cases it is not only slow but if there were no obsolescence or inadequacy it would probably give good service for many years. But as it continues to wear out, and as repairs are continually made in the endeavor to keep the property up as near its original value as possible, it is probable that the average of the lack of repairs on a whole property would approximate 15 per cent or if the property were maintained in very high class condition the average of this lack of repairs might be 10 per cent. It is utterly impossible, however, that taken at any moment, the value of the whole property could be 100 per cent of its original cost. I am speaking now, of course, of the original property only and not additions thereto. Therefore, in order that the capital may be maintained at its full value, it will be necessary to have accumulated a surplus or depreciation fund, or renewal fund, covering this 15 per cent, or the capital will be reduced in value just that amount. There is another method which Mr. Floy has touched upon but which I think deserves a little larger notice and that is what he calls the " fifty per cent method " of depreciation. This is only applicable to such large numbers of items of the same kind or nature as depreciate in common and as they wear together through a cycle of repairs, get into one general average condition, for it can be mathematically proven that when a number of articles such as a number of street car motors have all been in the shop for putting into thoroughly good order, the value of these motors new may be decreased by one-half of the total cost of the total repair on a motor; that is, the value of each one of the lot will be first, the total value of that portion of the motor which can not be depreciated, or that portion we might say which is always worth scrap value, or may be said to be worth a certain arbitrary value, say 25 per cent, of the cost new, plus one-half of the cost of the total repair to the motor; that is, the cost of repairs to everything that can be repaired.

Speaking electrically, the question of depreciation in connection with arc lamps, meters, and pole transformers should be given thorough consideration in any valuation, for the reason that these smaller items change in type so fast, wear out so soon, and are changed around so much that they are of no value at the end of 10 years, and often in much less time. In fact, I believe the larger companies depreciate them fully 1/10 per annum, for the reason that they go out of style so soon and that new forms are produced to replace them which are so superior that no excuse can be found for holding over the old ones.

It would be interesting to learn how Mr. Floy would treat the property of the Massachusetts street railways some of the values of which have been entirely wiped out by re-organization. For example, take the property of the Springfield street car system which was a good type of horse railway, and when it was electrified nearly the entire property then existing had to be abandoned, the horses sold, the car houses rebuilt or removed, the stables destroyed or used for storehouses, the track entirely reconstructed, and to this cost was added that of the power-houses, new car houses and new cars, all of the old ones being of no use under the new construction.

If an appraisal of the property of the Springfield Street railways were to be made at this moment the only values found would be those of the electrified property and nothing would be found of the original possessions covered by the first capitalization except the land. The question is, what has become of this original capital, and still further, what has become of it on the books of the company, or how has it been treated by the Massachusetts Railway Commission? It is the writer's view that an amortization fund should have been established to gradually wipe out the original capital, or perhaps better say, the cost of the original road.

As a matter of fact, we are all merely guessing at depreciation and its extent as no electrical apparatus has yet been installed for a time long enough to determine its actual life. I think I am safe in saying that no one in this room has ever seen a worn out corliss engine and it was the writer's pleasure recently to have seen the first three-phase dynamo installed; that at Redlands, Cal., which was put in place in 1895, I believe, and is still doing most excellent duty.

J. G. Hirsch: Probably no discussion is of more general interest to the engineering profession than one covering some phase of what might be styled engineering finance or accounting, such as that by Mr. Floy. The ultimate analysis in most engineering undertakings is in dollars and cents, and the weakness of engineers on cost and its analysis is an old story. The advent of Public Service Commissions and the necessity for satisfactory, detailed discussion of the financial aspects of especially the power projects of today must force the engineer to the fore on the subject, due to the fact that he has the pre-requisite understanding of the technical considerations.

In making estimates, I feel certain that it has been the custom of many engineers to give little more consideration to provision for, and operation of, depreciation, than to setting down a certain rate for the interest on the investment as a fixed charge.

The application of the terms depreciation, obsolescence and amortization has been bewildering to me. This much can be said, that they all *operate* as a charge on the operation of the enterprise. The acceptance of a single term, depreciation, and its proper definition, reduction of worth, will eliminate confusion. The term should not be confounded with the annual depreciation " charge ", which is made to provide for the " loss of worth ", or the " depreciation fund " or " depreciation reserve fund " (the latter to distinguish from a sinking fund)which has accumulated up to a given time in the life of an item. In my opinion it is not wise to generally consider a depreciation fund as related to a sinking fund in the sense of a provision for contingencies. The provision of a sinking fund proper has its own field. In this connection I gather that Mr. Floy would combine provision for depreciation and the cost of maintenance and repairs in one item of charge. I regard a depreciation charge as one of fixed annual amount, based on the assumed useful life of the property; maintenance and repairs are quite dependent on the particular service required of the plant, and the attention given in its proper care. The amount of charges for maintenance and repairs is then dependent on the operation of a plant or property in much the same way as the care of firing a boiler, for instance, will determine the fuel cost. Then is not a charge for maintenance and repairs properly an operating charge? It is admitted that in the case of an extended system with numbers of similar items, the distinction between maintenance and repair charges, and depreciation charges, may be considered of such minor importance as to be dropped in accounting, but the principle remains, for the extended system is quite the exception to the rule.

While I agree with Mr. Floy that the application to be made of figures for depreciation charges should be known when the figures are decided upon, I feel that the underlying principles which determine the figures are definitely fixed except in very special cases. In this connection he designates certain reductions of worth as theoretical and others as absolute. If the value of a plant is to be estimated for any purpose it is only fair to consider its remaining useful life in fixing the value. The value of a property is, therefore, directly dependent upon its remaining useful life at the time. It seems to me that this proposition is no different from the purchase of a horse on the basis of age. From the financial standpoint, with proper management and accounting, the sum of plant value and the depreciation fund, at a given time, equals original investment. A going plant maintains practically constant profit earning power throughout its useful life, about as indicated by Curve 6 of the paper, dropping off slightly during the period of life owing to loss of efficiency and deterioration which cannot be removed by repair. Also, an abstract lot of plant equipment drops off in value immediately after purchase, about as shown by Curves 1 and 2 of the paper. Now as plants or other engineering works are built with the intention of their being operating business propositions over the period of their useful life at least, and as the *remaining total earning power* becomes less year by year in direct proportion to the life remaining, therefore, the value of the property must decrease uniformly throughout the period. The facts remain even though no depreciation fund is maintained, where a faulty business management fails to make provision for keeping the investment unimpaired, as in the case of many municipalities which, once the lighting or water works plant is in operation, provide appropriations sufficient to cover running expenses only, interest on the investment being usually paid from a general fund, and depreciation not at all provided for until demanded by the maturity of the bonds. When estimating the cost of production or operating expense in reporting upon a proposition, or when investigating an operating plant, charges for depreciation are uniformly distributed over the period assumed as limiting its useful life, in order that capital may be returned at the same rate that remaining total earning power decreases.

The above considerations argue for *uniform* reduction in worth as the actual depreciation of a going plant, (uniform depreciation charges, such as indicated by Curve 3, or the straight line method) and as the practical and logical method of providing a depreciation fund, as against Mr. Floy's designation theoretical to this method.

The method indicated by Curve 4 is a legitimate distortion of Curve 3, developed by the financial consideration that all idle funds should be put out at interest. A method such as that represented by Curve 5 is a distortion of the real principles of providing for depreciation, developed for special considerations in accounting or business administration.

In considering obsolescence, any difference in value of an item, at the time of its replacement, and its salvage or scrap value, should be charged as capital added to the investment in new equipment replacing the old. If the replacement is not a good investment when burdened with this charge, it is not justified. This point is clearly expounded in a paper on industrial power costs by M. O. Jenkins of the New York Edison Company in the June 20 issue of *Power*.

I am of the opinion that any figures which might be collected for the life of plants or apparatus would be very unreliable unless accompanied by statements of the economy of the apparatus and the cost of maintenance at the time of replacement. Deferred maintenance will greatly shorten, and extended maintenance and repair will considerably lengthen the life of property and equipment. It has been my experience that industrial concerns and municipalities which do not regularly maintain technical supervision do not rightly appreciate the propriety of alterations and replacements to increase economy and better service; as long as a property runs without failure it is satisfactory, even long after its useful life has expired, as evidenced by decreased efficiency and excessive maintenance charges.

I suggest that it would be most valuable to standardize averages for economical and useful lives of various equipments and structures as indicated by the judgment of engineers of broad experience, through coöperative work by the three Nattional Engineering Societies.

Alten S. Miller: I feel constrained to discuss Mr. Floy's paper briefly for the purpose of accentuating a few of the many good points, and for the purpose of going on record as differing from the author in certain other points. There are many important truths found in the paper they should be carefully studied and understood by every engineer who undertakes to estimate the reproduction cost and the rate of accruing depreciation of any piece of property.

Under Development Expenses, etc., it is stated: " Any one of these terms is generally used to include certain expenses, which, while a necessary part of the complete cost of a going property, are not costs inherently a part of the construction of the physical property, as such."

This statement is somewhat ambiguous. It is well known to every engineer and investor that the plant cannot be built and the property put on an earning basis without these expenses. Such being the case, they are an essential part of the cost.

In view of the general lack of understanding of this subject, it would be well if engineers would always include the overhead charges in making statements of cost, and make a special note if they are not so included.

Under Good Will Mr. Floy states: " A monopoly, as is generally admitted, has no good will which can be evaluated." In the first place, no gas or electric light company is a monopoly. As a rule they are under different managements so that the customer may always use gas or electricity for light or power, assuming that there are no competing gas or electric companies in the territory. In addition, illuminating oil, gasolene and private power plants provide efficient sources of light and power which are sufficient to make people independent and to prevent any one company from securing a monopoly. This being the case, anyone who has managed a large gas or electric property knows that there is such a thing as Good Will and that good will has a very great value.

Mr. Floy criticizes the action of many companies in charging to capital account replacements due to obsolescence.

An examination of the electric light and street railway properties of the larger cities of the world, shows that the property has depreciated so rapidly through obsolescence that few of the companies have earned their interest and depreciation. A quotation is given from the opinion of Justice Brewer, delivered in 1904, as follows: " It is not always reasonable to cast the entire burden of the depreciation on those who have invested their money in railroads." Under many conditions the capitalizing of property that replaces other property which has become obsolete is not only not an error but is eminently proper from the point of view of the investor and the public.

Obsolescence is shown in one of two ways: Either the service is not abreast of the times and the demand, or the operating expenses are too high. Assuming that either condition has been produced by inventions subsequent to the installation of the plant and that the earnings have not been adequate to permit the investment to be written off, it is to the advantage both of the investor and the public to discard part or all of the old plant and capitalize the replacements. The public thus has increased facilities for which it is proper that the company should be compensated; or economies are realized, the advantage of which may be enjoyed by both the investor and the public.

The table given assumes that the property is profitable from the beginning, and that the company can afford to set aside $160,000 each year for interest and depreciation. In view of the fact that few if any of the public service corporations are so fortunate as to earn interest and depreciation during the first years of operation, the real course to be followed in justice to the investor and the public lies between the two plans shown in the table. The depreciation as well as other losses in the early years should be capitalized until the property is earning all expenses including depreciation and an adequate return on the investment.

The author states: " if no depreciation fund is set up, nothing can be included in the cost of operation as necessary to provide for depreciation."

This is partly covered by my statement in the last paragraph. If a company is not earning enough to take care of its depreciation, it is, nevertheless entitled to take the accruing depreciation as a part of its cost of service in any question of rate regulation. A company is warranted in paying interest on its bonds and floating indebtedness before providing for depreciation, and in some cases it is wise to pay dividends on stock in order that additional amounts of money may be raised to develop the property, although if the full amount of depreciation were provided for, such dividends would not be earned. These questions must be settled by the managers of each property and cannot be governed by any general rules.

The author makes the statement: " From the cost should then be deducted this absolute depreciation in order to obtain the present real or service value of the property."

In determining depreciation, is it not safer to estimate the amount that will be required to put the apparatus into a condition that is practically as good as new and call that amount " depreciation " rather than to decide that the machinery is worth say 50, 60 or 70 per cent of its original cost, and to call the difference between one of those figures and the original cost the depreciation? The former is the usual process followed.

The 50 per cent method quoted in the paper is so seldom applicable that it seems hardly proper to quote it as a method having any merit. If there is a piece of property that is not growing and the maintenance of which is uniform from year to year, it is a curiosity. Certainly this method would not be applicable to a growing property or to a case wherein the methods of construction are improving as replacements are made. It is not applicable therefore to the poles, cross-arms and braces of an electric company.

Inasmuch as small transformers, meters and arc lamps have been replaced largely through obsolescence, this rule is not applicable to them. In the case of boilers it may be found that a certain percentage of tubes are replaced each year, but it will be found on inspection that a large portion or all of these tubes will be on the first and second rows, numbered from the bottom. The tubes above this may be 100 per cent efficient, and it would be a serious error therefore, to say that the tubes as a whole are only 50 per cent efficient.

In the case of a gas company the amount spent for maintenance of mains and services might be the same each year, but the depreciation will be found on examination to be due to some local condition, and a large part of the work of maintenance will be done in a few localities. The rest of the pipe system will be in condition as good as new or 100 per cent. Under these conditions it would be grossly improper to say that the distributing system as a whole is only 50 per cent efficient. On the whole it is highly improbable that there is a single case anywhere in which such a method would be properly applicable.

It is stated: " While usually preferable there exists no necessary reason for always writing off certain costs such as engineering, incidentals, etc., at the rate at which the physical property of which they are an inherent part, is depreciated."

It is somewhat difficult to understand exactly what is meant by this paragraph. Replacements usually require engineering and when completed the cost will usually be found to contain many incidentals. In other words, these items are elements of the cost of replacements as well as of the original construction, and to this extent allowance should be made for their depreciation at the same rate as allowance is made for the depreciation of the other values of the inventory property. Such replacements will not affect the design of the property as a whole, and to this extent it is not necessary to depreciate the general engineering and incidental expenses.

In conclusion I will summarize briefly my opinion on the points in which I disagree with Mr. Floy.

Development expenses, intangible or overhead values, are an essential part of the cost of construction of physical property and should be included as such.

Electric light and power properties do not have monopolies, but may have " good will " which latter has a very real value.

It is proper in many cases where corporation earnings have not been sufficient to maintain the property, to capitalize replacements.

If the earnings of a corporation are not sufficient to set up a depreciation fund, it is nevertheless proper for purposes of rate making to include a fair estimated cost of depreciation.

The easiest and safest method of determining depreciation is by estimating the cost of putting the property in a condition substantially as good as new.

The 50 per cent method of estimating depreciation requires so many qualifications and has such a narrow application as to make it very unsafe.

The engineering costs, incidentals, etc., that would probably be involved in connection with replacements should be written off with the physical property in connection with which the expenses have been incurred.

Frank F. Fowle: Mr. Floy's paper on depreciation is notable for its careful analytical treatment of a subject that seems in danger of becoming hackneyed, but which, as he points out, needs more extensive illumination than it has yet received. An examination of the literature on the subject reveals a great mass of material which treats of life tables and associated matters, but little which is specific on the side of theoretical analysis.

The term depreciation is a generic one, meaning the " act of lessening or crying down of price or value," or " the falling of value; reduction of worth." The broad term has been loosely employed in a great many instances with different specific meanings. There is thus great need, as Mr. Floy emphasizes, of careful qualification and definition; and in order to promote mutual understanding among engineers, lawyers, economists and accountants there ought to be established by common consent, a comprehensive and authoritative nomenclature.

In view of the great importance of the subject it is suggested that a special committee of the Institute might be appointed to formulate definitions and stimulate discussion of those phases of the matter which need it; or the Electric Lighting Committee might carry out such a program.

The common confusion between maintenance and depreciation arises, fundamentally, because there has never been devised or applied a thoroughly scientific system of depreciation accounting. It doesn't seem to me that the plan of lumping maintenance and depreciation helps the case any, because there are so many maintenance expenses that have nothing to do with depreciation and are not related in any way to the life of the plant.

In the strictest view of the matter any renewal, however trivial, ought to be charged to depreciation, but in practice it is difficult to do this and as a rule only heavy or important replacements go to depreciation. For example a life of twenty years might be assigned to a certain Corliss engine and it might turn out to be the actual life, but during that time various minor parts would wear out and be replaced, perhaps several times, and the cost charged to maintenance. The problem is to determine how far we ought to go in subdividing a property into its elements or component parts, in classifying renewals as depreciation or maintenance. Two very important purposes of a depreciation fund are to maintain undiminished assets behind the stock and bonds, as the plant wears and depreciates, and secondly to maintain an even annual charge against revenues to take care of replacements and renewals. Other purposes can be mentioned, but these are fundamental. If they are substantially met there can be no argument except over questions of a more purely technical nature.

But this involves the vital question of how property depreciates, or how fast and in what manner it passes from its value new to its scrap or salvage value, when the life is assumed or known. This question Mr. Floy discusses under the head of "absolute" and "theoretical" depreciation. The absolute depreciation of public utility property which forms part of a going concern he defines as curve No. 6 in Fig. 1 of the paper, while the theoretical depreciation might be one of the curves No. 3, No. 4 or No. 5.

There is here a marked difference between two definitions of present value, taken at any time during useful life. The theory represented by curve No. 6 is given in the paper and in substance amounts to this:—that a property which is maintained at approximately full efficiency, without unreasonable expense, throughout its useful life, is substantially worth its cost new, or original cost, up to or very closely approaching the time of its abandonment. That is to say, it is able every day to render the same service and do the same work at undiminished efficiency. Or in other words, present value is measured by a state of readiness to serve or ability to give immediate service, without regard for the future time during which that service can be sustained. On this theory there is very little if any depreciation on a property which is reasonably well maintained.

But is this a correct economic view? We must go back to the definition of value and examine its elements, in order to arrive at any conclusion. The economic definition of value is power in exchange; utility or usefulness is one of the important elements and always present, although it does not, alone, establish value. Ely classifies the elements of value as follows.

Value {
Elementary, as in raw materials.
Form, as in manufactured products.
Time }
Place } created in retail trade.

In the case of a going public utility, whose business may be assumed to exist through the future years indefinitely, the element of *usefulness*, in its relation to plant value, seems to be most important. For example, such a concern could afford to pay twice as much for a generator (of a given size) which would last 30 years as it could for one which would last 15 years, assuming equal efficiency and maintenance cost. Or again, if the generator which had a 30-year life were 15 years old and in a normal condition of maintenance, the company could afford to pay as much for it as for the new generator which had a 15-year life.

Stating this principle in more general terms, the total usefulness is as much an element of value as immediate usefulness. A state of readiness to serve, without regard for the ability to render prolonged service, is not then the full measure of value; it is naturally an element of value and must be present, but after that it is remaining years of useful life which determine the plant value in a going public utility.

I have never been able to find a sound economic argument for such a theory of present value as that corresponding to curve No. 6 of Fig. 1. Total usefulness seems to me to be the great controlling element, and as that usefulness expires progressively with the rendering of service day by day, so it seems to me the value must expire also.

B. E. Sunny: Every paragraph in Mr. Byllesby's splendid paper is worthy of special notice and comment, but there are two paragraphs of paramount importance.

The first one is with reference to State Commissions.

Originally the idea of State Commissions met with great opposition among the utility companies, for the reason that they had been accustomed to dealing with the State and local municipal authorities, and they did not know whether they would be dealt with fairly by the new body or not.

The splendid record made by the Wisconsin and other Commissions has almost entirely changed the opinion of the public and the utility people with respect to the value of Commissions, and there are few now who do not endorse the State Commission idea of municipal management.

One thing that makes it possible for the State Commissions to deal intelligently and fairly with utility companies is that they are far removed from active politics.

In the City of Chicago, the handling of telephone and gas rates by the City Council during the past two years, during which time nothing has been accomplished, has been seriously interfered with by political considerations.

As a matter of fact, the utility companies as a rule have nothing to fear from either State or City regulation, or by Commissions, inasmuch as that perhaps not more than 5 per cent of the total number are earning in excess of operating expenses a proper charge to depreciation and a fair return on the investment.

Most utility companies are for the time being content if they are able to pay 7 or 8 per cent dividends, but they have either wholly or partially overlooked depreciation and obsolescence, and are making little provision for either.

As a matter of fact, the State Commissions, made up of intelligent experienced business men and engineers, are needed for the aid and guidance in the commercial management of utility companies quite as much as they are needed to protect the public from either bad service or extortion.

The other point in Mr. Byllesby's paper is to the effect that estimates covering new construction are usually too low, and the cost of the work runs all the way from 10 per cent to 100 per cent in excess thereof. This is of course within the experience of every one engaged in construction work.

The suggestion is pertinent that in appraising plants the same percentage of error ought to be taken into account.

In a recent letting in Chicago for caissons for a new office building, six bids ran from $140,000 to $203,000 or a difference of 30 per cent.

In the building of the Sanitary District Canal, some years ago, the work was cut up into sections, and let to a dozen or more contractors. All but one of the contractors failed.

We may or may not know how the contractor comes out on the caissons at $140,000, and we may or may not know how great a loss most of the contractors made on the Sanitary District work. We are likely however to be influenced by, and to make use of corresponding figures when they are applicable for the purpose of appraising work, with the result that a serious injustice is done.

Indeed, I regard it as unsafe to permit one individual or firm employed by the municipality, to appraise a utility property for rate making purposes. I think that in such cases, the utility company should be allowed to have an appraiser to represent its interest, and before the work is begun, the two appraisers should select an umpire to settle the differences which will inevitably arise. It is only in this way that the error to which Mr. Byllesby refers can be at least partially guarded against.

The paper by Mr. Floy is one of the best contributions to the subject of depreciation that I have seen. It brings us down to date on a vital item in the handling of a public utility.

It is significant that Mr. Floy makes no argument with reference to the existence of depreciation. This indicates progress. A dozen or fifteen years ago, there were many who did not believe that there was such a thing as depreciation. Now it is generally recognized. Even today however, depreciation has not taken its proper place in the utility accounting. In good times, depreciation receives liberal treatment out of the satisfactory earnings, while in bad times, when the earnings are scant, it is forgotten. This at least is true of the utility companies, of which as I said above, there are few that are really making any profit where proper charge to depreciation is included.

I am rather in hopes it will not be very long before the practice will become general of including a charge to depreciation with the same regularity and care that we charge to operating expense, interest and dividends, and have the fluctuation with reference to good times and bad reflected in the surplus account.

Halbert P. Gillette: Mr. Floy has presented an interesting discussion of the very important subject of depreciation, particularly from the viewpoint of the appraising engineer. Not only because the author of this paper has mentioned the writers' name in connection with the application of plant mortality tables, but because the writer may be able to add some information on the general subject of depreciation, does the writer offer a discussion of a paper read before a society in which he is not a member.

To begin with, the writer does not use the term depreciation in the sense it is used by the author. The author's use of the term makes it include both the cost of current repairs of parts of each plant unit and entire renewals of whole plant units. The writer uses depreciation to denote the cost of renewal of whole plant units only, and this, he believes, is the sense in which the term is now used by nearly all public service and railway commissions that have had to do with many appraisals of public utilities. Due to the fact that there is still no entire uniformity of practice in the use of the term depreciation, it seems desirable either to adopt the present rather general practice of using it to mean cost of renewals of plant units, or else to adopt the word amortization in its place.

A plant unit is a structure or machine which, for accounting or appraisal purposes, is regarded as a unit; as, a building, a car, a boiler, a railway cross-tie, etc.

The author proposes the expression "theoretical depreciation" to denote the cost of renewals of plant units, but the expression is too cumbersome for convenience in use.

In the second edition of his "Handbook of Cost Data," the writer called attention to the great desideratum of uniformity of practice among engineers in the use of the word depreciation. He also pointed out that while the renewal of entire plant units does not differ in principle from the renewal of parts of the same units, it is desirable to record the costs separately. Thus, the repairs of a locomotive may average 18 per cent of its first cost per annum, while the renewals of entire locomotives may average 4 per cent. The 18 per cent is a repair item, while the 4 per cent is a depreciation item, and the sum of the two, 22 per cent is the total cost of maintenance. Many engineers have made serious blunders in estimating the cost of maintenance by using published depreciation percentages under the mistaken idea that they included current repairs as well as renewals. In fact, engineering literature is replete with examples of just such blunders.

Shall depreciation be deducted from the cost of reproduction new to obtain a plant value that shall be used as a basis for rate making? This is an ever recurring question, and one that grows daily in importance. The writer's own answer has been that depreciation shall be deducted from the new value, but that it must usually be added on again in the form of development expense. The writer uses the term development expense in a sense different from that used by the author of this paper. The writer's definition is:

Development expense is the accumulated deficit in fair return, from the start of operation of a plant until a fair return begins to be earned.

There are some appraising engineers who call this the "going value" instead of development expense, but the term "going value" means so many different things to different men that it is not a desirable term to use.

As an example of the method of calculating development expense, Tables I and II will serve. Table I is based on the assumption that no depreciation has occurred. Table II is based on the assumption that there has been depreciation.

Table I gives an example of a plant assumed to cost $100,000 and to begin operating January 1, 1900. For the sake of simplicity it is assumed that there have been no additions to the original plant. To begin with, assume that there has been no depreciation, and assume that 8 per cent is a "fair return". Then we have the results shown in Table I.

The deficits, column (5) of each year are the development expense of that year, and the total development expense is $5,144, so that at the end of the development period, December 31, 1904, the total value of the property is the cost of the plant, $100,000, plus the development expense, $5,144, or a total of $105,144.

TABLE I

(1) Year	(2) Value Jan. 1	(3) Fair return at 8%	(4) Net earnings from operation	(5) Deficit	(6) Value Dec. 31
1900	$100,000	$8,000	$6,000	$2,000	$102,000
1901	102,000	8,160	6,500	1,660	103,660
1902	103,660	8,293	7,200	1,093	104,753
1903	104,753	8,380	8,000	380	105,133
1904	105,133	8,411	8,400	11	105,144
				$5,144	

Now let us assume that there has been an actual depreciation of $15,000 in the plant value, as disclosed by an appraisal. Then from the actual net earnings should be subtracted such a sum annually as to provide (at 8 per cent fair return) an amount equal to $15,000 at the end of the year 1904. This would be $2,556 deducted annually from the net earnings shown on the books. Table II gives the result of the calculation on this basis.

TABLE II

(1) Year	(2) Value Jan. 1	(3) Fair return at 8%	(4) Net earnings	(5) Sinking fund	(6) Deficit	(7) Value Dec. 31
1900	$100,000	$8,000	$6,000	$2,556	$4,556	$104,556
1901	104,556	8,364	6,500	2,556	4,420	108,976
1902	108,976	8,718	7,200	2,556	4,074	113,050
1903	113,050	9,044	8,000	2,556	3,600	116,650
1904	116,650	9,333	8,400	2,556	3,489	120,139
Total					$20,139	

Table II shows that the total deficit, or development expense, is $20,139 based on the assumption of depreciation, which if added to the depreciated value of $85,000 gives a total of $105,139

Contrasting the results of the methods derived from Tables I and II, we have:

	Table I	Table II
Plant value	$100,000 (new)	$ 85,000 (depreciated)
Development expense	5,144	20,139
Total value	$105,144	$105,139

Had the calculations been carried out to one or more decimal places, the final results would have been identical. We see from this illustration that the development expense calculated on the assumption that the plant has depreciated exceeds the development expense calculated on the assumption of no depreciation, and that this excess is precisely equal to the amount of the depreciation that has occurred during the development period.

There is very much more to the subject of development expense than is likely to occur to one who has not applied it in many cases, but it would lead to such a digression from the subject of depreciation that the writer can not touch upon it further than to point out how it serves to solve the problem of giving justice to a public service corporation that has not provided a sinking fund with which to wipe out the depreciation that an appraisal may show.

Rarely has any large corporation, public or private, provided a depreciation fund with which to recover any considerable part of the loss in plant value due to depreciation. What rational appraising engineer or public service commissioner would contend that a sinking fund should have been established to provide for the loss of value of cross-ties in a railway track? Cross-ties in a track, if properly maintained, ultimately attain an average value of about 50 per cent of their cost new; but who will urge that a sinking fund should be established to provide for a 50 per cent lost value, when the " service value " of the ties is as great at any time as on the day they were first laid? Obviously no one would so contend, unless it were proposed to sell the railway as one would sell a second hand machine, which is a thing that neither the railway owner nor the public contemplates. What holds true of cross-ties holds true of many other plant units. In any event, the writer's method of calculating development expense (as indicated in Tables I and II) shows clearly that if the public intends to be just in its treatment of public service corporations, it must either regard the plant as being worth its actual new cost, or it must permit the corporation to revise its old operating accounts, from the day the plant began operation, so as to include an annual allowance for depreciation, which shall fully cover the past depreciation disclosed by a present day appraisal. This is but common justice, and, when such justice is measured out, it results inevitably in an increase of the development expense by an amount equal to the depreciation, as above shown.

The writer may add that he believes there is a startling surprise in store for the public—a public that has been woefully misled by recent articles in popular magazines as to the extortionate profits made by railways and other public utility corporations. The writer's appraisal of the railways of Washington made it clear that in that state the railways were not robbing the people, and were, in fact, averaging a return that no merchant, manufacturer, or farmer would be contented with.

The writer has recently been engaged on the appraisals of five street railway and interurban electric railway systems, not one of which shows a return on the investment that would satisfy the business men of the communities in which they exist; in fact, the accumulated deficit in fair return, assuming as low as 7 per cent for a fair return rate, has been more than 40 per cent of the aggregate cost of the physical property of these electric railway plants, in spite of the fact that the plants (with one exception) have been long established and are in growing communities. In other words, the development expense of these five electric railway systems has been more than 40 per cent of their first cost, and is not ended yet. Moreover—and this is a matter of extreme importance—this 40 per cent development expense is calculated on the assumption that there has been no depreciation; but, with an adjustment of the accounting records to include depreciation (amortization) as a part of the operating expense, the percentage for development expense becomes much greater.

The writer has observed with growing interest that other appraisals of electric railways all point toward the conclusion that that railway is fortunate indeed that can develop a sufficient business to yield a fair return on the cost of the physical property without incurring a development expense (a going value expense) of at least 30 per cent of the cost of its physical property new. And, if, as seems likely, the average depreciation of all electric railways is about 20 per cent, as determined by appraisal on the straight line theory, then the development expense will average about 50 per cent of the cost new, which is to be added to the depreciated plant value to obtain the total value of the plant and its going business. No man can say exactly what the average percentage will ultimately be found to be, but it is evident that not merely the public but experienced engineers will be surprised by the facts that are now in process of disclosure as a result of numerous electric railway appraisals.

The author of this paper gives a table of rates of depreciation used by different appraisers, and he speaks of them as having, in effect, "largely become law." This is apt to be misleading, for, of course, the use of a rate of depreciation by no appraiser gives it even the semblance of law, nor does the acceptance of an appraiser's estimate by a public service commission add much to the credence that engineers or court should necessarily give to the truth of the figures.

Many of the rates of depreciation given in the author's table are rates based upon engineering guesses as to the life of machinery, and the life is a life determined by obsolescence or inadequacy.

The writer found that the life of locomotives and cars used by several large railway systems had averaged 28 years. It is quite generally known that many locomotives are in use on European railways after a life of more than half a century, showing that depreciation of locomotives in America has been almost entirely a matter of economic inadequacy. Locomotives are quite typical of other machines. With the exception of a few plant items that depreciate by rotting, such as wooden cross-ties and poles, and a few items that depreciate by abrasion, such as rails, trolley wire and pavements, there are scarcely any items given in the author's table that have a depreciation rate that has not been estimated on the basis of life lost through obsolescence or inadequacy. This being so, it becomes illogical to attempt to appraise the depreciation of many items of a public utility by mere inspection. The writer believes he was among the first, if not the first, to take cognizance of this point in making an appraisal of great magnitude. At least the writer was the first engineer of a public utility commission to abandon entirely any attempt at inspecting all the property of public utilities to determine the depreciation. The writer prepared plant mortality tables of all classes of plant units, and from the age of the plant units deduced the depreciation. A description of the method and discussion of the reasons for its use are given on page 1295 et. seq. of the writer's " Handbook of Cost Data."

The author is wrong in his statement that the writer used what the author calls the " fifty per cent method of depreciation." What the writer did do was to call attention to the fact that all depreciable plant, where there are numerous plant units, ultimately depreciates 50 per cent of its wearing value if the plant is properly maintained; and, in the absence of any knowledge whatsoever as to the average age of plant units, it would be reasonable to use the " fifty per cent method " where inspection of plant units indicates that the " fifty per cent method " would yield approximately correct results.

If wooden cross-ties, for example, have been so long in use as to attain a rate of renewal equal to the reciprocal of their total life in years, then it amounts almost to a certainty that their average depreciation is 50 per cent, by the straight line formula. However, even in the case of ties, the writer has seldom been forced to guess, but has found it possible to deduce the average life either from the accounting records or from the engineering records.

As for inspection of such plant units as wooden ties or poles to determine depreciation, the writer can find little good reason, No man can look at the average tie or pole in use and tell its probable remaining life within a wide margin of the truth. A far closer estimate can be made if the average age is known.

Field inspection of wear of rails, trolley wire, etc., is more satisfactory, but even that can often be largely eliminated. Thus, for rails or trolley wire, careful measurements of wear due to a known number of cars will disclose the rate of wear; and from such data can be calculated the probable future life of other rails or trolley wire if the average density of traffic is known. But the life of rails is not always a function of the rate of wear, so that neither inspection nor calculation based on wear measurements will always disclose the true depreciation. Increased weight of rolling stock has been a most potent factor in causing rail renewals in the past, for rails have become inadequate because of the greater wheel loads they have been required to support. Nor is this all. Just as one change in chemical composition of rails led to the replacement of iron by steel, so other changes are now causing replacement of common steel by steel alloyed with ferrotitanium and other metals.

View the whole subject as we may, we are driven inevitably to the conclusion that inspection is apt to be a very misleading method of determining depreciation for almost any kind of plant unit, and that for most kinds of plant units inspection is the most misleading method that can possibly be used. No amount of inspection can show the rate of depreciation due to obsolescence or inadequacy.

A very strong argument can be made in behalf of estimating depreciation solely on the rate of loss of life due to wear, tear and disintegration by natural forces. While this method is seemingly to be desired by public service corporations whose property is being appraised for purposes of rate making, it proves to be a boomerang the moment consideration of the maintenance expense begins, for then a corporation naturally and rightly wants to be permitted to take out of earnings enough to provide for depreciation due to obsolescence and inadequacy.

The writer believes that no man can accurately estimate *future* depreciation due to obsolescence or inadequacy, but the only safe and fair way is to base future estimates of depreciation on past experience. Then the rates of depreciation thus deduced should be applied both in appraising depreciated values and in providing sinking funds or depreciation reserves out of earnings. It may be demonstrated mathematically that a public service corporation, the weighted age of whose depreciable plant is less than $\frac{1}{R}$, is the gainer the higher the rate of depreciation assigned to the plant, R being the rate of fair return. Thus, if the rate of fair return R, is 8 per cent (0.08) we have $1 \div 0.08 = 12\frac{1}{2}$ years as the critical age. If the weighted age of the plant is less than 12½ years, then the more the estimated depreciation rate exceeds what it actually should be, the greater is the corporation the gainer by the error, provided the same rate of depreciation is used in estimating allowable amounts for sinking fund deposits. This formula $N = \frac{1}{R}$ for ascertaining the critical age can readily be proved true by the application of algebra, or by taking a few specific numerical examples.

Nearly all public service corporations, and steam railway companies in particular, have failed in the proper presentation of their cases to commissions and courts. This has been due to their ignorance of the problems of appraisal and rate making. They have fancied that their own operating engineers, officials and attorneys could readily prepare both the data and the arguments. Never was a more serious blunder made. Their engineers have usually not deeply studied either appraisals or rate making, and their lawyers have usually understood neither end of the problem. Finally, railway commissions themselves have often erred, because, while they have regarded appraising as being an engineering problem, they have not always regarded rate making as also involving equally important engineering problems.

Depreciation, as we have seen, affects not merely the problem of appraisal, but it gravely affects the matter of estimating operating expenses. The operating expenses of any single year are usually not typical, that is, they may be either higher or lower than an average over a long term of years, due to variations in the cost of renewals of plant units—*i.e.*, depreciation costs. When a plant is young its current repairs are smaller than they will be later on, and renewals (depreciation costs) are usually absent entirely in a young plant. It is an engineering problem, therefore, to determine what the maintenance expenses are going to be, and therefore it is an engineering problem to estimate proper allowances for maintenance during a typical or average year. No other kind of a year can be justly used as a basis for rate making. This is not the only reason why rate making is largely an engineering problem, but, even if it were, it would be sufficient reason why expert appraising engineers are needed not only in making appraisals of existing property but in appraising maintenance expenses.

Railway corporations have usually failed to secure an adequate allowance for " going value " or development expense. Most of them have secured no allowance at all, entirely because they have made no careful study of appraisal problems. They have often lost their development expense and with it has gone also that part of the development expense due to depreciation. They have known intuitively that they were being deprived of their rights under the guise of law, but they have not been able to give adequate reasoning for their belief in the injustice they were suffering. Driven to extremes they have often lied about the value of their physical assets, when they could have secured all that they were fighting for in the way of total values by merely proving their development expense from their own accounting records.

Recently the Wisconsin Railroad Commission has adopted a modified form of the above described deficit method of calculating development expense, and the commission has ruled that in calculating development expense the old operating costs of a company must be increased by a sufficient sum to cover the actual depreciation. This is one of the most important steps ever made by a public utility commission, and probably marks the beginning of the general adoption of a wholly rational method of ascertaining that hitherto elusive element of cost—development expense or " going value ".

Whether past depreciation should be amortized from future earnings or not is largely a matter of sentiment. In fact, whether development expense (going value) should be amortized or not is also a matter of sentiment. It probably will make little difference either to the public or to the public service corporations what procedure is adopted, for whether development expense remains as a source of revenue to a company or whether it is amortized, the company will get its *quid pro quo*.

Henry Floy: The rather close connection and joint discussion of Mr. Byllesby's and the author's paper, sometimes makes it difficult to analyze and reply to certain of the speakers' arguments.

The careful and lengthy discussions of the paper under consideration, by men of such prominence as those who have contributed, indicate the wide-spread interest and importance of the subject; at the same time clearly substantiating the authors opinion that there exists a notable lack of uniformity of nomenclature and a wide diversity of opinion in matters relative to " Depreciation."

The author appreciates the efforts of several of the contributors in their attempts to clarify and properly define terms. This would be more acceptable were it free from a spirit of sarcasm apparent in the discussion of one participant, but so out of place before an engineering society. Aside from any attempted definitions which may be purely academic or put forth as a species of mental gymnastics, most engineers agree with the author that utility has a value which may be expressed in dollars. If not, the values indicated by the curves Nos. 3, 4 and 5, in Fig. 1, may not be expressed in dollars any more than curve 6, and the only value that may be attached to the property being appraised, if the term relates exclusively to barter and sale, is the second-hand or scrap value, which all informed engineers will agree is not the basis on which any appraisal has been or is being made for determining the physical values of an operating concern. Because John Stuart Mill years ago, or other political economists, once attached a certain meaning to the word " value " does not signify anything with regard to the present use of the noun. Words change their meaning daily, and the word " value " may properly be used to measure utility, the original value of which has perhaps been determined through purchase.

As has been suggested by several speakers, the Institute could appropriately take under consideration the proper definition of terms used in connection with the subject of " Depreciation," coöperating with the other national societies in this matter. The National Electric Light Association has already a committee at work on this subject.

Several prominent engineers indicate that in their opinion, for rate making purposes, certainly, the basis for valuation is the cost of the physical property reproduced as new, plus certain development expenses. This is a very satisfactory showing and indicates decided progress. Mr. Arnold explains and accepts this basis frankly, while Mr. Gillette comes to the same conclusion through the inclusion of what he unfortunately terms " development expense." His application of this term to what has generally become to be known as " going value " and has been so used for years by the Wisconsin Commission, will hardly be accepted by informed engineers. Mr. Gillette himself seems to find it necessary to use " going value " to explain what he improperly calls " development expense ". It would seem as if those who differ from the author in the use of terms or definitions set out by him, should advance sound argument for substitution of terms they propose rather than mere expression of preference, or what they have been accustomed to do as against the wider use and more general custom, which the author has attempted to follow.

As stated by the author, the tables showing accepted rates of depreciation, which include as a rule some allowance for obsolescence and inadequacy, cannot be applied indiscriminately, and must be used conservatively. They are given as indications of what has been done; in fact much of the entire paper has been written to show the line of procedure heretofore followed. It would seem that we can only advance by a thorough understanding and knowledge of what other people are doing in treatment of the subject of depreciation, and these tables are given because they show figures which have been approved in important cases, and what fairly may be expected by those who are interested in operating companies when they have to appear before commissions or courts. The readjustment of rates based on the use of such figures and their acceptance both by the Public Service Commissions and public utility companies, certainly establishes them much more firmly than mere engineer's opinions, and gives them in effect the semblance of law.

Considerable of the discussion apparently relates to methods of procedure applicable to newly organized or recently started companies, where either the application or omission of theoretical depreciation can be, made without injury to the interests of those who have invested their money. This condition, however, does not apply to old corporations and it is unfair to take advantage of those who have already invested their money, and are unable to take it out, to apply too strictly rules such as those covering theoretical depreciation, where such application will result in the confiscation of property running into perhaps millions of dollars. This is evidenced for example, in the case of some engineers who, while claiming that curves Nos, 3, 4 or 5 Fig. 1, are those to be used in determining the present value of property, are very careful to avoid trying to demonstrate the absolute accuracy of any one of the three curves, although the use of one or the other would result in a difference of several millions of dollars, as has been shown for example, in the valuation of street railway properties in New York City. The use of one curve or the other, admittedly, is largely one of preference or convenience, and being based on an assumed theoretical life always results in discussion in the endeavor to prove the truth of the assumption, which is not absolute.

Several of the speakers apparently failed to grasp the author's distinction between " absolute " and " theoretical " depreciation, and the fact that these are *both* considered in determining present value only, that " theoretical " depreciation alone is used in determining annual rates of exhaustion of life. Mr. Hoxie seems unable to appreciate that a yearly rate of depreciation has nothing whatever to do with the total absolute depreciation, and his illustrations as to rulings of Commissions, assume an ignorant commission unable to revise its rulings, as it finds the amounts laid aside for depreciation are larger than required. Further, he seems unacquainted with the very wide practice of corporations and the rulings of at least one Public Service Commission, practically prohibiting the building of extensions out of excess earnings, which many consider contrary to the best policies now in vogue. Of course the author was endeavoring to cover the usual case that exists and not the exceptional. covered by the illustration. The author has not conceived of " two separate rates of depreciation " applied to the same property, nor does he agree that the appraisal must include a deliberate judgment of the value of useful service remaining as it is present service, not future service, which the public is interested in, and upon which the rate of return must be based. In the Consolidated Gas case, the Supreme Court did not tell us to figure two kinds of depreciation. It did tell us to figure one kind of depreciation, and that is what the author has called " absolute " depreciation, which is to be used in determining the present value, on which rates are based. It did tell us that no " theoretical " depreciation should be deducted in establishing the basis on which to estimate fair return. In the Knoxville Water case, the Court clearly states that the original investment, regardless of " absolute " depreciation, is not the basis for figuring a fair return, and furthermore that proper allowance, as a part of operating expenses, should be made to cover the wasting away of physical property. Mr. Hoxie evidently agrees with the engineer of the Public Service Commission, that it is a very easy matter to appraise the Third Avenue R.R. by the " 50 per cent method ", which basis the Public Service Commission accepted in part, and obtained a depreciated value which does not compare with the value or appearance of the property to anyone who knows it, and demonstrates as well as anything can that " theoretical " depreciation is purely theoretical.

Mr. Foster states that " repairs are continually made in the endeavor to keep the property up as near its original value as possible ". This is evidently an over sight by Mr. Foster, as of course he recognizes that repairs are made not for the purpose of keeping property up towards its original value, but to maintain it in good, operating order. He is also mistaken in stating that " It is utterly impossible that taking at any moment the value of the whole property could be 100 per cent of its original value " as it can be easily recognized that a sudden rise in the value of real estate of a marked difference in the price of labor and material could easily result in showing by appraisal, the value of the property at 110 or more per cent of its original cost. In fact the values of 75 per cent or 85 per cent so frequently used as that of property in good condition depends on how much of the physical property is of long life, or whether the relative amount of total investment is largely in real estate or road-bed, which increases rather than decreases in value with age.

With regard to the Springfield Street Railways, the author entirely agrees with Mr. Foster that the investment in horse properties should have been amortized out of earnings, if the latter was sufficiently large to permit such amortization, otherwise the value of the horse railways must be left in the capitalization, as indicated in the paper under " Total Depreciation " for example, although nothing of the original physical property remains for identification.

Of course ordinary wear and tear maintenance, renewals, replacements, obsolescence, inadequacy, must be taken care of eventually as a part of operating expenses, and paid for by the public; there can be no question on that point if investors are still to be found willing to put their money in public utility properties.

At first thought and superficially, it would seem that the sum of the plant value (the present value determined by appraisal) and the depreciation fund (where one is necessary) should, at a given time, equal the original investment. As a property kept in good operating condition will ordinarily not be found to be in a condition below 75-85 per cent of cost of reproduction, a fund larger than 15-20 per cent would never be required even on the theoretical basis proposed by some engineers, and as a practicable matter, a sum equal to 3-5 per cent of the original value, would ordinarily be amply sufficient for a property uniformly maintained.

The ambiguity, if such exists, which Mr. Miller seems to find with regard to the author's separation of development expense from physical values, doubtless arises from the attempt to include with the physical values, those percentage items which are practically fixed and uniform in all cases, such as engineering expense, allowance for incidentals, omissions, etc., and to put in a separate class under the head of development expense, those items which vary widely with local conditions, and individual management. There certainly was no suggestion that development expenses were any less a necessary part of the total outlay required than were the physical costs, but the engineering expense for example is practically always 5 per cent, while the costs of obtaining a franchise or the legal expenses, must be figured for the actual case under consideration and vary widely. It would hardly seem fair in view of the statement made in the paper under " Total Depreciation ", to state that the author criticizes the action of companies in charging to capital account replacement due to obsolescence. This is only so in case the earnings have been sufficient to write off the obsolescence Mr. Miller says " Depreciation, as well as other loses in early years should be capitalized until the property is earning all expenses." Certainly the Public Service Commissions and engineers generally will not agree with this statement unqualified, as it would mean that poorly managed or evidently ill advised investments should be allowed to continue capitalizing losses indefinitely. There must be some limit to the capitalization of these early losses, and while a legitimate and reasonable amount may be capitalized if the earnings are too small to cover the depreciation and obsolescence, such procedure comes close to encroaching on dangerous and unstable ground. It would be interesting for Mr. Miller to cite cases in which depreciation has been determined by estimating the amount " required to put the apparatus in a condition that is practically as good as new " for certainly it is not " the usual process."

The advance copies contained some typographical errors so that the clause quoted by Mr. Miller is not clear; it should have read " while usually preferable, there exists no necessary reason for always writing off certain costs, such as engineering, incidentals, etc." the author's view being apparently in accord with Mr. Miller's, namely that original engineering expense need not necessarily be written off with the depreciation of the physical property which may be renewed without such engineering expense. For example the renewal of rails in track would be done by the operating force without any special engineering expense; therefore the original engineering cost remains in the property, regardless of the physical condition of the rails. Practically the same method of determining going value, (called " development expense " by Mr. Gillette, and shown in his tables 1 and 2) has been recognized and used by the Railroad Commission of Wisconsin for some years. It has strong claims for consideration, and if judiciously used, is applicable in many cases. Mr. Gillette truly states that no amount of inspection can show the rate of depreciation due to obsolescence or inadequacy, but neither can theorizing determine the rate. If Mr. Gillette proposes to determine all depreciation from records and computations made in an office, it would seem as if his results were entirely theoretical and hypothetical. As it is practically impossible for any engineer to determine the amount of " theoretical " depreciation from an inspection of apparatus, does not the whole question of such depreciation, which must be based on examination of records as to dates of purchase, with an assumption as to probable life, result only in speculative values; which while possibly of service in determining the price for bargain and sale, has nothing whatever to do with the value on which capitalization should be based or rates fixed, provided an inspection proves the property is well maintained.

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INDUCTION MACHINES FOR HEAVY SINGLE PHASE MOTOR SERVICE

BY E. F. W. ALEXANDERSON

The experimental results and investigations presented in this paper have the object of showing the possibilities of operating polyphase motors from single-phase circuit, particularly with a view of the use of such a system where heavy starting duty is required. At various times there have been suggested schemes for changing single-phase current into polyphase current for such purposes, but those schemes have never been taken very seriously on account of their ineffectiveness in producing a balanced polyphase current.

The reason why the author feels justified in presenting these data to the Institute is, that he has succeeded by the scheme described in producing a balanced polyphase current by an apparatus which, in cost and weight, is only a fraction of the driving motors, the motors being ordinary polyphase motors with the same starting and running characteristics as such motors used on ordinary polyphase circuits.

EARLY TYPES

A well known scheme, often thought of in connection with changing single phase current to polyphase, is the use of an induction motor, as shown in Fig. 1. Two terminals of the induction motor are connected to the single phase line, whereas, all three terminals are connected to the driving motor. If the first mentioned machine, which may be classified as a " phase converter ", runs at full speed it generates a polyphase voltage which is available for starting the driving motor. However, the output of the phase converter is very unbalanced, and the starting torque of the motor is so much reduced that the system has found application only in exceptional cases.

The theory of the phase converter can be treated with greater facility if both machines are considered as quarter phase instead of three phase machines, and this assumption will, therefore, be used in the following:

Considering the quarter phase connection, as shown in Fig. 1, it is apparent that phase *A* is fed directly from the line, whereas phase *B* of the motor is fed through the medium of the windings of the phase converter. In other words, whereas the working current in phase *A* of the motors needs to flow only through one winding, the working current in phase *B* must flow through three windings, that is, phase *A* of the converter, phase *B* of the converter and phase *A* of the motor. The net result is as shown by theory as well as tests, that the maximum starting torque of such a combination is between 45 per cent and 50 per cent of the torque of the same motor fed from a polyphase circuit. Under those circumstances it would be impractical to use such a scheme for starting and accelerating duty, because the maximum output of the driving motors is usually the limiting feature of the design.

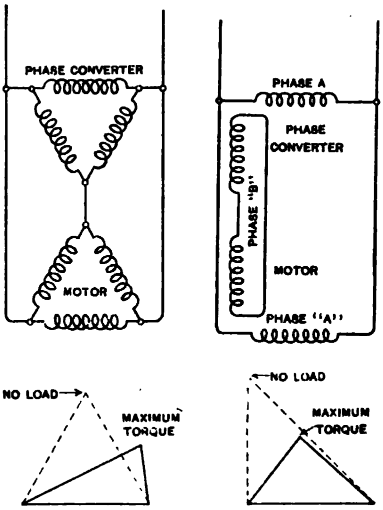

FIG. 1

NATURE OF THE IMPROVEMENTS

The scheme presented by the author is a development from the induction phase converter shown in Fig. 1; however, with the introduction of such improvements that the starting torque of the main motors is the same as on polyphase current instead of less than one-half of that value.

The reason for the ineffectiveness of the phase converter in accordance with Fig. 1 is the voltage drop in phase *B*, and, furthermore, the phase displacement between the voltage of phase *B* and the voltage of phase *A*. The starting torque of a quarter-phase motor is proportional to the product of the voltages on phase *A* and phase *B* multiplied by the sine of the phase displacement between phase *A* and phase *B*. To illustrate this, it can be said that the starting torque is proportional to the triangle representing a complete polyphase voltage impressed upon the motor. The voltage triangles for an induction phase converter delivering current under the conditions of maximum torque of the motor is shown under the corresponding diagrams in Fig. 1.

It is evident, at first sight, that the voltage at the terminals of the motor is very far from a balanced polyphase voltage. In order to improve these conditions it is necessary to correct the phase displacement as well as increase the current in phase *B*. In attempting to accomplish this, the first improvement which suggested itself was to connect the motor in series with the phase converter. In doing so the phase converter is forced to act like a series transformer between phase *A* and phase *B*, transforming the current from one winding to the other and displacing it at the same time by approximately 90 deg. This arrangement in itself effects a considerable improvement because the phase converter, looked upon as a series transformer, maintains a comparatively good ratio between the primary current and the secondary current, and the ratio of currents and phase displacement rather improves by increasing load, whereas, the secondary voltage in the multiple connection decreases rapidly at increasing load. As a net result of this arrangement, according to experiment, it can be stated that the starting torque is about three-quarters of the starting torque with polyphase current. Such a result, although a considerable improvement, would scarcely be acceptable. The reason for the lack of effectiveness is the fact that all the lagging current that must be supplied to phase *B* of the motor must be transformed twice by the phase converter, passing from stator to rotor and back from rotor to stator, thereby causing a considerable drop in voltage.

The method which has been found to overcome this difficulty is to interpolate in phase *B* a voltage, derived from the line, so as to create artificially a phase displacement between the output of the phase converter and the input of the motor. By doing so the phase converter is allowed to give an output of leading current instead of lagging current, whereas, the motor receives lagging current as before. It should be noted that the current flowing in the two machines is the same, but it has the effect of lagging current in one and leading current in the other on account of the artificial phase displacement between the voltages. The result is that the current output of the phase converter is not demagnetizing, but tends to increase the voltage, and, in fact, as will be shown in the following, the voltage and current of the secondary phase can be entirely regulated by selection of a suitable voltage for interpolation between the windings. The diagram of connections is shown in Figs. 2 and 3. In Fig. 2. an autotransformer is used for supplying the interpolated voltage whereas in Fig. 3 the line voltage is used, while phase *B* is eventually wound with a correspondingly greater number of turns.

GENERAL THEORY

Next to the fact that the system is operative the most important question to be answered is, what are the characteristic curves and the efficiency and power factor of the combination.

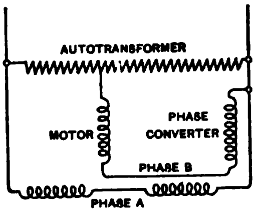

FIG. 2

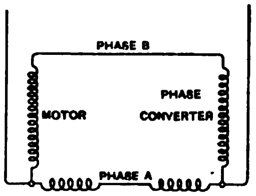

FIG. 3

There are two methods of analysis that could be employed for such a problem; a complete mathematical analysis of the electrical energy components, and the synthetic method dealing only with input and output and losses.

The mathematical analysis of a machine like the ordinary single-phase induction motor and even the transformer have led to considerable literature, and new contributions to the same are being made all the time. It, therefore, appears that even in problems where the methods are as well agreed upon as those mentioned, there is considerable latitude for the personal point of view of the investigator. The problem before us is a good deal more complicated than those mentioned, and for this reason the complete mathematical analysis will not be attempted, but the paper will be confined to the statement of the premises and deriving the most important results by a synthetic method. In dealing with direct current the synthetic method is extraordinarily simple and used exclusively. All that needs to be considered is the energy terms, input, output and losses, which are all measured in watts. With alternating current there are the wattless components to be considered which are measured in volt-amperes. There seems, however, to be a law for dealing with wattless volt-amperes which is almost as definite as the conservation of energy. For practical purposes it can be stated that all the wattless volt-amperes delivered to a circuit can be traced as losses of volt-amperes or outputs of volt-amperes in some parts of the circuit or of its subsidiary circuits connected to the same by induction or rotation. A certain quantity of volt-amperes can be changed to another quantity by change of frequency on account of relative rotation of the winding. The quantities are, however, strictly connected by the relative frequency, so that it may be said that the volt-amperes divided by the frequency is a fundamental quantity or magnetizing effort, which follows a law analogous to the conservation of energy.

A magnetizing effort can be generated only by a battery, commutator or other rectifying device, and is usually introduced in alternating circuits through a magnetic field excited by a direct current furnished from the commutator of the exciter. Wherever commutators occur in an alternating circuit allowances must be made for the magnetizing effort generated by these commutators. However, in the cases of purely inductive circuits like those in the problem before us, the law applies without an apparent exception. Each alternating field consumes a definite amount of volt-amperes for its excitation, and each current flowing in windings consumes a certain amount of volt-amperes due to its leakage reactance. All that is necessary in order to find the power factor of a certain combination of alternating fields, is to sum up the volt-amperes needed to excite the field, and the leakage volt-amperes created by the current in the windings. These volt-amperes added together constitute the total wattless volt-amperes of the machine combination. The energy components are figured in the ordinary way, adding together output, core losses and copper losses as determined by the currents flowing in the various circuits. After finding in this way the total energy input and the total wattless kilovolt-amperes, the total input is found as the square root of the sum of the squares of the energy input and the wattless input. The power factor can then be found as the ratio of energy input to total input.

In order to use this method it is evidently necessary to know the strength of the various fields and the values of the various currents. However, it is not necessary to know the phase relations between the fields and the currents, or the relative phases of currents and voltages. The values of the individual quantities are comparatively easy to ascertain, whereas, a knowledge of the phase relations requires a complete mathematical analysis of the components. Applying the above to the phenomena in the machine combination shown in the diagrams, Figs. 2 and 3, there are only two currents to be dealt with.

Phase winding *A* of the motor is connected in series with phase winding *A* of the phase converter, and it is only necessary to assume a value of current for those two windings. The corresponding value of current in phase *B* could be determined graphically or mathematically in accordance with the vector diagram, Fig. 4, but for the sake of calculating the power factor it is only necessary to know, as an experimental fact, that the voltage interpolated in phase *B* through the winding of the main transformer can be regulated so as to give the same current strength in phase *B* as in phase *A*.

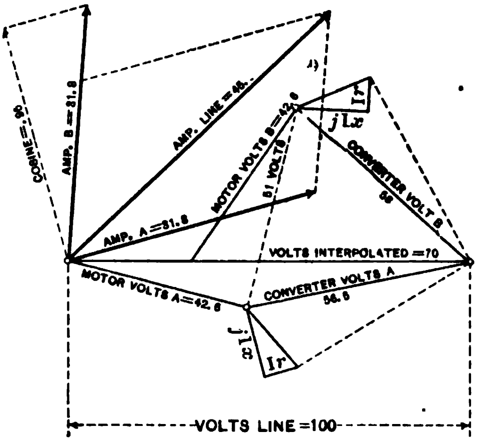

FIG. 4.—Vector diagram for starting condition

If the magnetization and leakage reactance of the phase converter as well as the motor is known, it is possible to figure out immediately the total wattless volt-amperes consumed by the alternating fields.

Fig. 4 shows the complete vector diagram for the starting condition. The resistance in the rotor circuit of the motor has been selected so as to give maximum torque for any given voltage. The values of voltages and currents are given with reference to a line voltage of 100 in order to make the information contained in the diagram more directly useful for application to any other voltage. In such a case, all the volts and currents should be increased in proportion to the voltages, and the kilovolt-amperes and kilowatts and torques in ratio of the squares of the voltages.

The voltage interpolated in phase *B* has been selected 70 per cent of the line voltage because it was found experimentally that this gave an equality of current in phase *A* and phase *B*. The phase relations as given on the diagrams are obtained from the average of several measurements made at different voltages, but reduced to 100 volts, as stated above. The diagram shows vectorally the current in phase *A* and phase *B*, and also how those currents are combined into the total line current, using 70 per cent of the current in phase *B* for one of the vectors. This is due to the ratio of transformation in the transformer supplying the interpolated voltage. The line current obtained in this way agrees in value as well as in phase with the line current found by ammeter and wattmeter measurements. In the diagram is also shown the phase displacement or deviation from exact quarter-phase relation. The cosine of the angle of deviation is 0.95. Hence, it can be concluded that the starting torque is reduced by 5 per cent from what it would have been with exact quarter-phase current.

CHECKING OF TEST RESULTS BY CALCULATION

Of all the factors that enter into the complete analysis, as indicated by the vector diagram, it is only necessary for practical purposes to be able to determine the following:

Amperes line.

Power factor line.

Torque.

It will, therefore, be shown how these quantities can be figured out from the fundamental data of the machine.

The machines used in this test were two 25 h.p., six-pole, 60-cycle, quarter-phase motors, with a normal voltage of 220. One of the motors used for the phase converter was provided with a squirrel cage rotor, and the other with a phase wound rotor and collector rings.

The following are the constants of the machine:

Motor exciting admittance	$0.014 + j0.095$	per phase
Motor impedance	$0.39 - j0.57$	" "
Phase converter exciting admit	$0.01 + j0.095$	" "
Impedance	$0.26 - j0.57$	" " .

In order to make these constants available in a convenient form for calculation of the wattless kilovolt-amperes and losses at various voltages and loads, the fundamental curves shown on Fig. 5 have been plotted giving the wattless kilovolt-amperes and losses per phase of the two machines. For the sake of convenience, these curves refer to voltage per phase of 100 and the corresponding values of current and kilovolt-amperes for any other voltage are found respectively by proportionality and square of the voltage ratio, as stated above. The fundamental curves for kilovolt-amperes per phase are figured as follows:

i_1 Amperes secondary	$i_1 E$ kv-a.	$i_1^2 x$ kv-a.	$\sqrt{(i_1 E)^2 - (i_1 x)^2}$ kw.	Watt-less kv-a.	Input kw.	Input kv-a.	Ampers primary.
0	0	0	0	0.95	0.1	0.96	9.6
10	1.0	0.057	1.00	1.01	1.1	1.45	14.5
20	2.0	0.228	1.99	1.18	2.09	2.35	23.5
40	4.0	0.912	3.89	1.86	3.99	4.42	44.2
60	6.0	2.05	5.64	3.00	5.74	6.47	64.7

The fundamental curves for the converter are also shown in Fig. 5 and are calculated in the same way.

Applying this data to the starting test it is found that the wattless kilovolt-ampere per phase of the motor at 46.2 volts and 31.8 amperes is 0.7 kv-a., the wattless kilovolt-ampere in phase *A* of the converter at 56.5 volts is 0.79 kv-a., and in phase *B* at 58 volts is 0.81 kv-a., making a total wattless kilovolt-ampere of 3.0. The input of the motor per phase is 1.31 kw., and the total losses in the converter are 0.26 kw., giving a total input line of 3.14 kw. If the kilowatts found in this way are combined with the wattless kilovolt-ampere the power factor is found to be 73 per cent. For comparison it can be stated that the measured power factor is 72.5 per cent.

So far it has been assumed in the above calculations that the motor is supplied with a true quarter-phase current. It remains to determine the phase displacement between the currents in the two phases in order to find the decrease of starting torque due to deviation from 90 deg. displacement. Actually this deviation depends only upon the magnetizing current in the converter. The motor, like any induction motor, is magnetized by the phase displacement between the current in the rotor and the current in the stator, whereas, the phase converter is magnetized by the relative displacement of stator current in phase *A* and phase *B*, or, to be more exact, by the deviation from quarter-phase relation. This is due to the fact that the load current that is absorbed by one phase is discharged by the other, so that the magnetizing current is leading with reference to the load current in one phase, and lagging with reference to the other. Thus the total displacement of the two currents is the sum of the two magnetizing currents. In the case represented by the diagram for starting, the sum of the magnetizing current of the converter is 10.2 amperes. Hence, the deviation from quarter-phase relation is the sine ratio of $\frac{10.2}{31.8}$ or 18.5 deg. The cosine of this is 0.95, or the same as has been found experimentally and as indicated on the diagram. The correctness of this theory has also

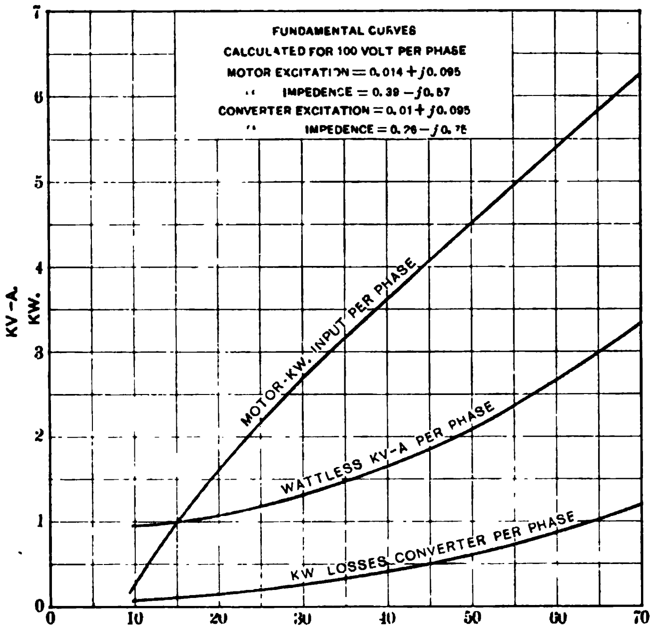

FIG. 5

been checked by direct measurements of torque with true quarter-phase current and with current furnished by the phase converter.

It should be observed that, although the decrease of starting torque of 5 per cent is for practical purposes inappreciable, the difference would be much smaller with a phase converter of such proportions as would actually be used, that is, of a high speed having a comparatively small magnetizing current. Assuming, for instance, that the magnetizing current relative to the output were one-half of what it was in the experimental tests, the correction of the starting torque would be 1.25 per cent instead of 5 per cent; in other words, quite negligible.

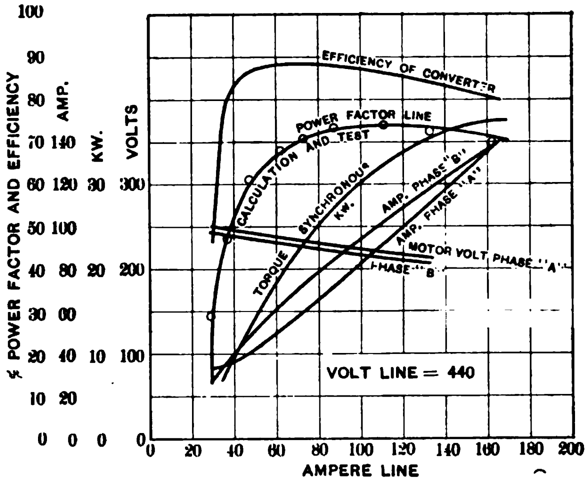

FIG. 6.—Characteristic curves—connection as per Fig. 2

Fig. 6 and Fig. 7 show the characteristic curve for the full speed running condition with interpolated voltages of 60 per cent and 100 per cent respectively. The curve for the power factor is calculated by the method described and the points found by measurement, indicated beside the curve, show the agreement of theory and measurements. The decrease of torque due to phase displacement depends entirely upon the magnetizing current of the converter, and is figured in the same way as for starting. It should only be observed that the correction must be made in watts input as well as output, whereas for starting, the correction applies only to output, the balance being wasted in the secondary starting resistance.

WEIGHT AND SIZE ESTIMATE FOR PRACTICAL PURPOSES

The tests previously referred to, which were made on two small 60-cycle motors, were undertaken to demonstrate the principle and confirm the theory and methods for calculations, whereas, the quantitative data derived from such tests would have no bearing on the conditions that would exist if the same were undertaken on a larger scale. The value of the system for practical purposes can be demonstrated only by showing the proportions of apparatus such as would actually be used. The system appears particularly to advantage when one phase converter can be used to furnish power to an aggregate of several motors. For this purpose designs have been made of a phase converter of a capacity corresponding to 1,600 motor h.p.

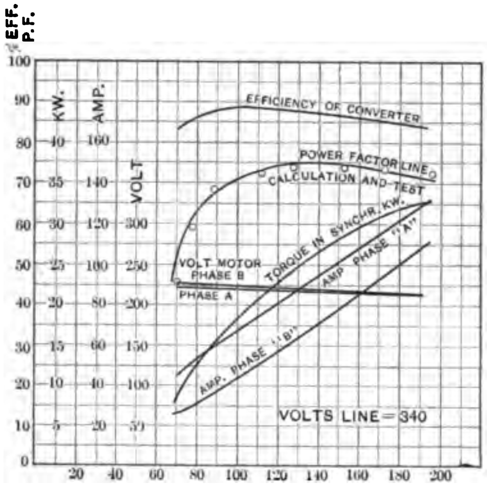

FIG. 7.—Characteristic curves—connections as per Fig. 3

In the first place, the relative proportions will be worth some consideration on general principles. Inasmuch as the energy of one of the phases of the driving motor is supplied by the line, the output of the converter must be substantially one-half of the polyphase capacity of the motor. In the tests described above this was the case, for the machines were of the same size, differing only, as stated, in winding of the armature. If it were proposed for operating conditions to use a phase converter with costs and weight the same as the main motors, the system would scarcely be acceptable. However, with the type of machines which would actually be used, it appears that the weight of the phase converter is only from one-third to one-quarter of the aggregate weight of the driving motors. The converter being a machine running light on its shaft without carrying any mechanical load, can be designed for the most economical speed, and it appears that this would be a peripheral speed which is twice as high as the peripheral speed of the motor. Furthermore, the weight per kilowatt is reduced because a single machine is used to serve an aggregate of several motors. For these reasons it is fair to assume that the active material in the phase converter is used at least twice as efficiently as the active material in the motors. The ratio between active material and total weight also favors the converter. In the motors, the ratio between active material and total weight is 30 per cent to 35 per cent, whereas in the phase converter that has been designed for corresponding purposes the ratio is 56 per cent. On the basis of these general considerations, it appears that the weight of the phase converter would be about 30 per cent of the aggregate weight of the motor. As an illustration of this a detailed design for a typical case shows a still more favorable ratio of 26.5 per cent.

Considering the electrical equipment as a unit there are some gains which partly offset the additional weight of the phase converter. With three-phase power the motors must be supplied from a three phase transformer, whereas, if single-phase power and a phase converter is used, the three-phase transformer can be substituted by a single-phase transformer. The weight of a single-phase transformer is about two-thirds of the corresponding three-phase transformer, and the difference covers an appreciable part of the weight of the converter. Altogether it can be estimated that the total increase in weight of the electrical equipment for single-phase power will be 15 per cent over the corresponding polyphase equipment with the same output and starting torque.

A comparison of the phase converter with a motor-generator set of corresponding capacity gives another illustration of the merits of the system. The single-phase capacity of the converter corresponds to the input of one phase of the motor, or one-half of the total output, whereas, the single-phase motor for a motor-generator set must have the full capacity of the equipment. Thus, the total aggregate capacity of the motors and generators for the motor-generator sets is four times as many kilowatts as the phase converter for the same power in the driving motors. On general principles it should, therefore, be expected that the weight of the motor-generator set would be four times as great as the weight of the phase converter. The figures available for the case under consideration indicate that the ratio would be even a little higher, or about 4.5 times, because the phase converter is favored by the very simple squirrel cage construction.

The converter being of the high-speed type designed for maximum efficiency of the material, it will also have a high electrical efficiency. The estimated efficiency in the instance given is between 96 per cent and 97 per cent. The wattless current absorbed by the converter is also correspondingly small, and the power factor of the combination can be expected to be considerably higher than the one shown in the tests described, particularly when 25 cycles are used instead of 60 cycles. The efficiency of the converter indicated above is an inherent characteristic of the machine, whereas the exact figures for power factor can be given only in combination with the particular motors that may be used.

In all that has been said and written about systems for power distribution, the expression " single-phase " has invariably been associated with commutator motors. It might, therefore, throw some more light upon the subject to consider that the possibilities of the induction motor for single-phase power are far from exhausted, although they have for a number of years been almost neglected or disregarded. Realizing that polyphase induction motors are by far the most economical form of power equipment, and that an addition of 15 per cent to the weight of the electrical equipment will adapt the same for single-phase power with the same output and starting torque, the subject might be reopened for serious consideration.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

ELECTRICAL OPERATION OF THE WEST JERSEY & SEASHORE RAILROAD

BY B. F. WOOD

The proceedings of our engineering societies abound in papers and discussions on the merits of steam and electric operation of railroads in which data are used, which to a large extent are lacking in figures taken from the actual cost of operation. A general impression prevails that operating officers of railroads will not consent to the publication of their operating costs. This to some extent may be true, but where such figures are correctly understood and properly used there should be no objection to their publication.

When the question of presenting certain data pertaining to the operation of the electrified portion of the West Jersey & Seashore Railroad before the American Institute of Electrical Engineers was discussed with the management of the Pennsylvania Railroad, the reply was made that not only would the information be furnished but that it would be a pleasure to have such information made public through the proceedings of the Institute. The following data were taken direct from the operating records with only such additions as would make them more readily understood. No effort has been made to curtail or to modify in any respect the data selected.

It is the object of this paper to present these data in as concrete form as possible without comparison with the operation of the parallel steam service, and no attempt will be made to analyze or compare the data with any that have heretofore been presented.

This paper will be of value if railroad engineers are encouraged to present before the Institute similar data, and if some standard form for the compilation of such data is agreed upon. Comparisons could then be made more readily and their value enhanced. It is hoped that a discussion will be developed which will

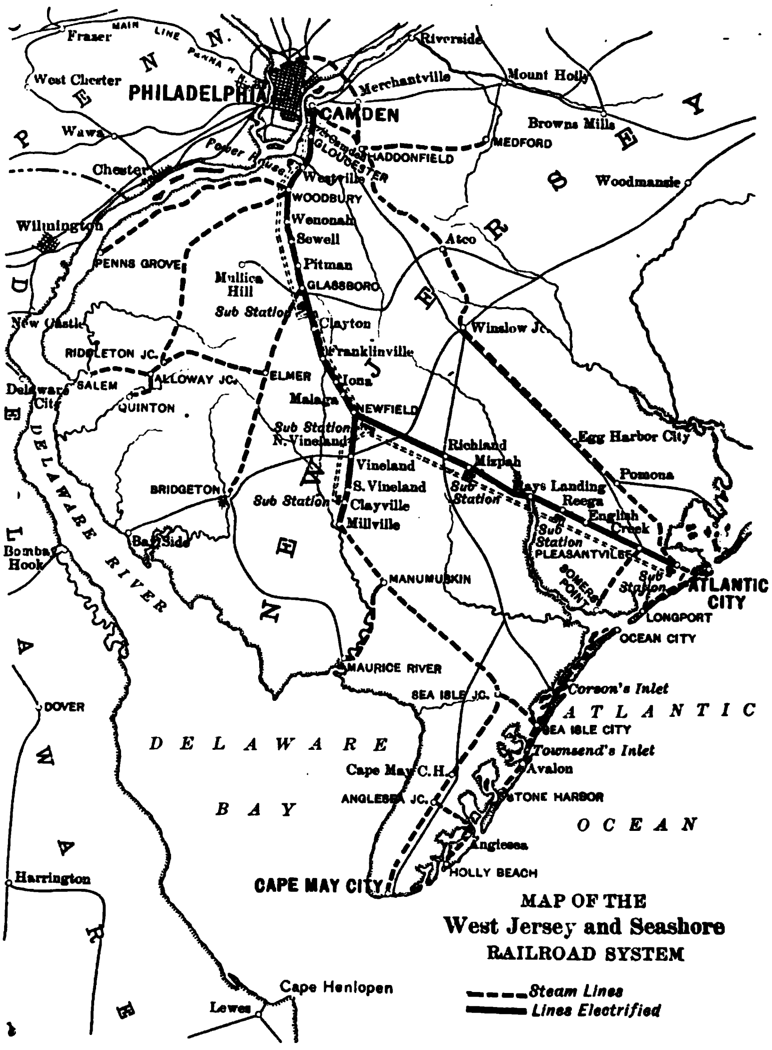

Fig. 1

enable operating officers and engineers to improve the efficiency, add to the reliability and reduce the costs of operation of electrically operated railroads.

No attempt will be made to describe in detail the construction used in the electrification of the West Jersey & Seashore Railroad as complete descriptions can be found by reference to the files of the Electric Railway Journal.[1]

The portion of the line which is electrically operated extends from Camden, via Newfield, to Atlantic City, a distance of 64.6 miles; and from Newfield to Millville, a distance of 10 miles. With the exception of the Millville Branch, which is a single track railroad, the line is double tracked with a third track extending for a distance of about six miles north from Woodbury.

This portion of the W. J. & S. R.R. was originally operated by steam and was a single track line south of Newfield. In the latter part of the year 1905 it was decided to electrify. The work was undertaken in December 1905 and had progressed to such a point that in the early part of July 1906 the first train was moved electrically. Regular operation by electric service was established in September of the same year.

The direct current over-running third-rail system operating at 675 volts was chosen for this installation.

A map of the West Jersey & Seashore Railroad is shown in Fig. 1, from which the electrified portion can be readily followed. The locations of the power station and the substations are shown, as well as the position of the transmission line with respect to the line of the railroad.

In order that the statements of cost of operation and detentions to train service may be more readily understood, the general characteristics of the electrified portion are given.

GENERAL DESCRIPTION

Track:

Main line, Camden to Newfield, double track, 100-lb. rails	30.2 miles
Main line, Newfield to Atlantic City, double track, 85-lb. rails	34.4 miles
Main line, South Camden to Woodbury, third track, 100-lb. rails	6.0 miles
Branch line, Newfield to Millville, single track, 100-lb. rails	10.0 miles
Total length of single track, including sidings	150.0 miles

Power Station:

Location: Westville, N. J., on Big Timber Creek, 5.6 miles from Camden Terminal. Rated capacity 8000 kw.

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[1] *Street Railway Journal*, November 10, 1906.
Street Railway Journal, October 12, 1907.

Equipment turbine room:

- Four 2000 kw. 6600 volt, three-phase, 25 cycle, Curtis turbo-generators.
- Twelve 700 kw. 6600/33000 volt, single-phase, 25 cycle, air blast transformers.
- Three 75 kw., 125 volt, Curtis turbo-exciters.
- Three 12 h.p. blowers, 20,000 cu. ft. per min. each.

Equipment auxiliary room:

- Four Williamson Bros. barometric condensers.
- Four I. P. Morris & Co., dry vacuum pumps.
- Four I. P. Morris & Co., centrifugal circulating pumps. (three driven by Reeves engines; one by Curtis turbine).
- Two Cochrane feed water heaters, each 539 cu. ft. capacity to overflow.

FIG. 2.—Power house at Westville, N. J.

- Three Worthington boiler feed pumps.
- Two Worthington make-up pumps.
- Two Worthington step bearing pumps.
- One R. D. Wood accumulator for step bearing, 800 lb. per sq. in , 100 gal. capacity.
- One R. D. Wood accumulator for step bearing, 100 lb. per sq. in.
- One Worthington oil pump.
- One Blake oil pump.

Equipment boiler room:

- Sixteen Sterling water tube boilers, 358 h.p. each, with superheaters
- Fourteen boilers equipped with Roney stokers.
- Two boilers equipped with Taylor stokers.
- Hunt gravity return system of coal handling used.

A general view of the exterior of the plant is shown in Fig. 2. In Fig. 3 a plan of the station is shown.

Transmission Line:

Length, 69.3 miles.

Line in duplicate, 33,000 volt, Y connected, neutral grounded.

Poles of chestnut, 45 ft. high, spaced 125 ft. apart—100 ft. at road crossings.

Head guys used every quarter mile, approximately.

Lightning protective ground wire strung on top of poles, 4 ft. above nearest wire, wire of 7 stranded steel galvanized cable, 5/16 in. diameter. Grounded every fifth pole.

Two cross arms on each pole. Top arm 12 ft. long carries 4 insulators; lower arm 8 ft. 6 in. long carries 2 insulators. Insulators 42 in. apart, forming equilateral triangle.

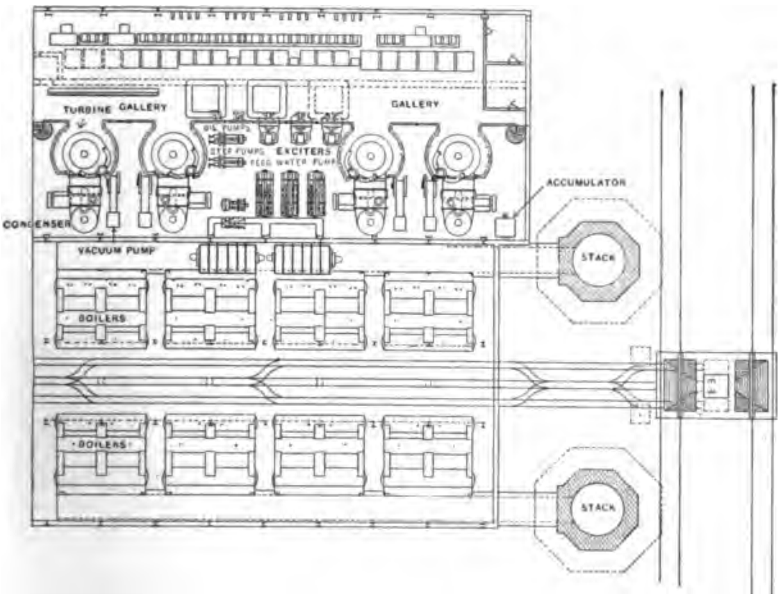


Fig. 3.—Plan of power house at Westville, N. J.

Wire, No. 1 B. & S., hard drawn, solid copper.

Wires transposed by one complete spiral between each substation, making a total of seven transpositions.

Signal line and lighting circuit. 1100 volt, single-phase, runs below 33,000 volt line from Camden to Newfield and from Pleasantville to Atlantic City.

Substations:

The high-tension, three-phase current is reduced in pressure and converted to direct-current at 675 volts in eight substations located as follows:

South Camden, 2.3 miles from Camden terminal.
Westville (in power house) 3.6 miles south from South Camden.
Glassboro, 12.1 miles south from Westville.
Newfield, 12.2 miles south from Glassboro.
Mizpah 10.9 miles south from Newfield.
Reega, 10.1 miles south from Mizpah.
Atlantic City, 12.5 miles south from Reega.
Clayville, 8.0 miles from Newfield (on Millville branch).

Equipment:

	Converters	Total cap.	Transformers	Alternating current line panels	Direct current feeder panels
South Camden	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	2
Westville	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	6
Glassboro...	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	4	4
Newfield....	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	6	5
Mizpah.....	Two 500-kw.	1000-kw.	Six 185-kw.	4	4
Reega.......	Two 750-kw.	1500-kw.	Six 275-kw.	4	4
Atlantic City	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	4
Clayville....	Two 500-kw. One 1000-kw.	2000-kw.	Six 185-kw. Three 370-kw.	2	2

Converters, 6-phase, diametrically connected, started from alternating current end in three steps.

Transformers air cooled, placed over air duct, supplied by two blowers.

Automatic oil line switches.

Multigap lightning arresters in all stations.

The plan and section of a typical substation are shown respectively in Fig. 4 and 5. Fig. 6 shows the exterior of the substation at Newfield.

Third Rail:

Length, single rail, main line and branch	137.12	miles
Sidings	4.61	miles
Total	141.73	miles

Rails:

Standard P. R.R. cross section and composition, 100-lb. per yd.

Conductivity equal to that of copper rod of 1,200,000 cm. cross section. Located 2 ft. 2 in. from gauge line of track and 3½ in. higher than running rails.

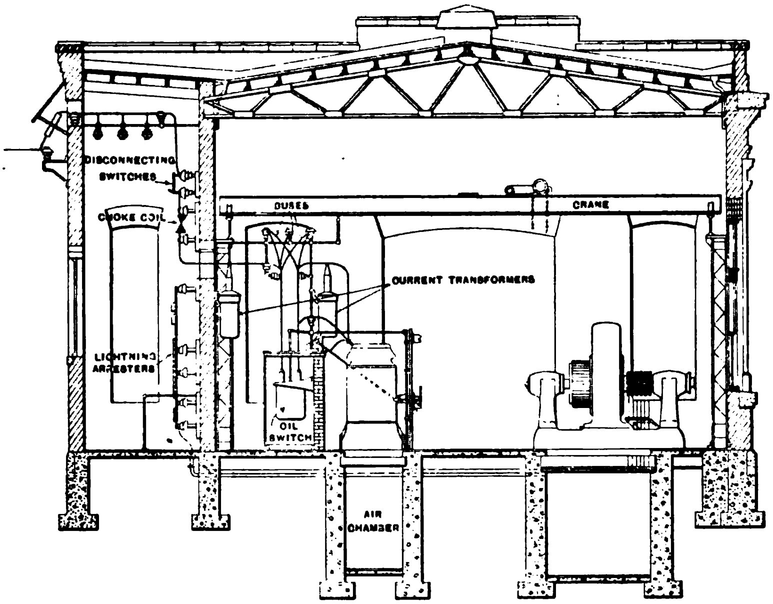
Contact made on top of rail.

Bonded with concealed ribbon bonds, solid copper terminals, pressed into one inch holes drilled in the rail. Two bonds per joint, 500,000 cm. each.

Road crossing jumpers consist of one cable per rail, of 1,000,000 cm., in bituminized fibre conduit laid in concrete.

Jumpers brought out of concrete posts with removable hoods and bonded to rail by two stub-end bonds.

Third rails are provided with protection boards at all stations and for 20 ft. on each side of all road crossings. At stations side protection boards are also used. Top board, two in. plank, supported on castings held by maple posts placed six ft. apart.



TRANSVERSE SECTION OF TYPICAL SUBSTATION

FIG. 4.—Transverse section of typical substation.

The third rails are sectionalized at each substation, each north-bound and each south-bound rail having a separate feeder.

The two rails are cross-bonded at three points between substations.

No feeders are used in connection with third rail.

In Fig. 7 is shown a view of the third rail approach block, the top and side protection for the third rail.

In Fig. 8 is shown the third rail arrangement at cross-over and shows unprotected as well as protected rail.

In Fig. 9 is shown a general view of the yard at Camden, in which all of the third rail is protected.

Trolley:

Length of single wire,

Main line	8.60 miles
Sidings	0.04 miles
Overlapping	0.91 miles
Total	9.55 miles

Wire is No. 4/0 grooved section, supported by $\frac{3}{8}$-in. galvanized steel stranded span wires at a height of 22 ft. above track rails.

There are two 750,000 cm. feeders, South Camden substation to Haddon Avenue, Camden, and one 500,000 cm. cable South Camden substation to South Gloucester.

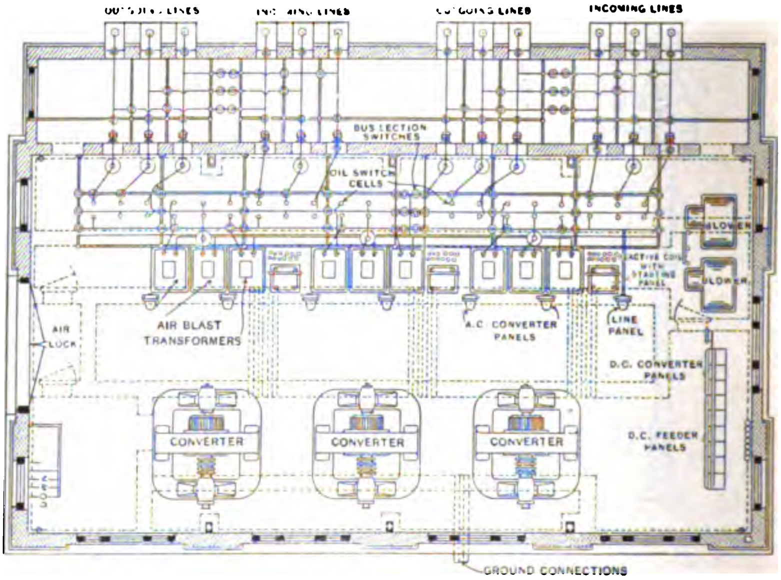


Fig. 5.—Plan of typical substation.

Track Bonding:

Concealed ribbon bonds used with solid copper terminals compressed into one inch holes drilled in the rail.

Two bonds per joint, 400,000 cm. each.

Special splice bars used to admit bonds.

Bonds tested every six months by means of millivoltmeters and Whitney Bond Tester.

Cars and Equipment:

Car equipment consists of:

79 coaches, seating capacity 58.
2 combined passenger and baggage, seating capacity 36.
6 baggage and mail.
6 baggage.

Total 93 cars.

Coaches weigh 94,500 lb. or 1,630 lb. per passenger.

Electrical equipment of each car consists of two 200 h.p. motors with multiple unit system of automatic control.

Gear ratio. 46:29.

Additional equipment has been authorized consisting of 15 steel coaches, having a seating capacity of 72. The cars will weigh 103,500 lb. or 1445 lb. per passenger.

Fig. 6.—Exterior of Newfield substation

Fig. 7.—Third rail approach block, top protection and side protection

Inspection Sheds:

All inspections and repairs made in Camden shed. Other sheds used for emergency inspection and light repairs.

Camden shed, three tracks, accommodates 9 cars.
Atlantic City shed, two tracks, accommodates 6 cars.
Millville shed, one track, accommodates 3 cars.
Third rail is not continued into sheds, overhead trolly being used.

FIG. 8.—Third rail at cross-over

FIG. 9.—View of electrified yard at Camden terminal

COST OF CONSTRUCTION

A table is included showing the cost of construction in connection with the electrification and includes costs made necessary by electrification. It will be noted that the electrification costs represent less than half of the total cost involved in the change of motive power.

Costs are also presented showing the unit costs of power station transmission line, substations etc.

COST OF CONSTRUCTION

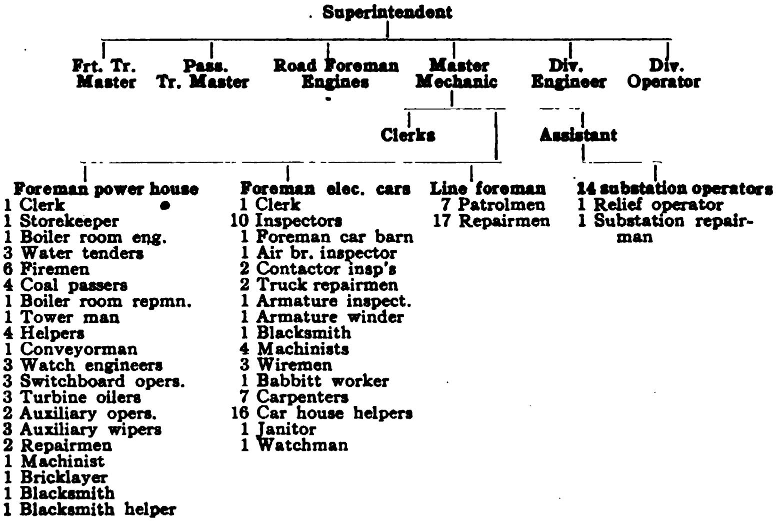
Power Stations:		
Building, stacks, coal and ash handling machinery	$354,000	
Equipment	640,900	
Total		$994,900
Transmission line		241,500
Substations:		
Buildings	72,000	
Equipment	419,560	
Total		491,560
Third rail		557,636
Overhead trolley		80,500
Track bonding		102,659
Cars		1,135,900
Car repair and inspection sheds		46,674
Right-of-way, additional		592,100
Reconstructing tracks		763,800
Constructing new tracks		2,071,000
Terminal facilities and changes at stations		252,400
Signals and interlocking plants		561,900
Changing telegraph and adding telephone facilities		105,100
Fencing right-of-way, cattle guards, etc		88,400
Miscellaneous items		44,200
Total		8,130,229

UNIT COST OF ELECTRIFICATION

Power station, cost per kw	$124.36
Transmission line, cost per mile	3,485.00
Substations, building and equipment cost per kw	28.90
Third rail, cost per mile	4,235.00
Overhead trolley, cost per mile	4,120.00
Track bonding, cost per mile	684.50
Cars, including electrical equipment each	12,214.00

ORGANIZATION

With the introduction of the electric service the organization of the road was not changed but was expanded to provide for the new duties. A chart of the Motive Power Organization is shown below, which shows the number of employees engaged in the various departments:



COST OF OPERATION AND MAINTENANCE

The cost of operation and maintenance is shown under several headings as follows:

1. Cost of operation in cents per car mile.
2. Cost of operation and maintenance of Westville power station.
3. Cost of maintenance of high-tension transmission line.
4. Cost of operation and maintenance of substations.
5. Cost of maintenance of third rail.
6. Cost of maintenance of trolley.
7. Cost of maintenance of bonding.

Table I shows the cost of operation for the years 1909 and 1910, in cents per car mile, and subdivides the cost of operation into the general headings, repairs, electric equipment of cars; repairs, passenger cars; other maintenance of equipment costs; electric power at car shoes; yard service, shifting cost; motormen; trainmen; train supplies and expenses; total of above; other expenses; total expenses. The table also shows the total car miles per month and the average cars per train. The headings of this statement are probably sufficiently explanatory, other than "other expenses," which includes cost of maintenance of way and structures, despatching trains, telephone and telegraph, crossing gatemen, together with traffic expenses and general expenses.

Table II shows the cost of operation and maintenance of the Westville power station for the year 1910. This statement is subdivided under the general headings of operation and maintenance and under the further sub-headings of material and labor. The statement shows the total monthly cost as well as the cost in cents per kw-hr. for each item.

TABLE I
WEST JERSEY & SEASHORE RAILROAD
Electric train service
Passenger train statistics
Cost of operation in cents per car mile
Year 1909

	Repairs, Electric Equipment of Cars.	Repairs Passenger Cars.	Other Maintenance of Equipment Costs.	Electric Power at Car Shoes.	Yard Service Shifting Costs	Motormen	Trainmen.	Train Supplies and Expenses.	Total.	Other Expenses	Total Expenses.	Car Miles, Total.	Average Cars per Train.
January......	1.06	2.05	0.48	4.78	0.51	0.93	1.53	1.20	12.53	10.25	22.78	279,210	3.113
February.....	1.07	2.42	0.38	4.63	0.51	0.91	1.49	1.22	12.63	10.99	23.62	258,130	3.163
March.......	1.18	1.97	0.35	4.99	0.52	0.99	1.65	1.18	12.83	10.17	23.00	279,193	3.092
April.........	1.26	2.03	0.25	4.43	0.46	0.89	1.40	0.61	11.32	9.14	20.46	317,963	3.483
May.........	0.84	1.73	0.26	3.98	0.44	0.88	1.45	0.45	10.03	9.18	19.21	318,006	3.482
June.........	0.40	0.68	0.31	3.58	0.25	0.86	1.41	0.42	7.91	9.35	17.26	339,294	3.530
July.........	0.33	0.44	0.12	2.82	0.20	0.80	1.25	0.40	6.36	6.95	13.31	478,203	3.669
August.......	0.28	0.40	0.14	2.75	0.20	0.75	1.18	0.36	6.06	6.29	12.35	517,223	3.921
September....	0.43	0.67	0.14	2.75	0.25	0.83	1.32	0.42	6.81	6.87	13.68	428,571	3.584
October......	0.64	0.71	0.24	3.84	0.31	0.92	1.53	0.62	8.81	10.21	19.02	307,825	3.046
November....	0.52	0.39	0.29	3.85	0.29	0.95	1.70	0.82	8.81	9.30	18.15	291,816	3.327
December....	0.87	1.08	0.29	12.31	0 30	1.00	1.72	1.30	18.87	15.05	33.92	292,175	3.318
Avg.........	0.68	1.10	0.25	4.30	0.33	0.88	1.44	0.69	9.67	9.08	18.75	4,107,609	3.457
						Year 1910							
January......	0.86	1.03	0.67	4.59	0.46	0.96	1.64	2.24	12.45	7.22	19.67	292,523	3.169
February.....	0.79	1.78	0.33	5.38	0.50	0.97	1.48	1.07	12.30	12.44	24.74	262,488	3.137
March.......	1.04	1.13	0.28	3.87	0.48	0.88	1.51	0.89	10.08	12.91	22.99	333,252	3.445
April.........	0.62	0.76	0.31	4.57	0.49	0.97	1.62	0.70	10.04	11.55	21.59	302,463	3.344
May.........	0.57	0.78	0.24	2.78	0.48	0.89	1.41	0.44	7.59	9.92	17.51	351,994	3.651
June.........	0.79	0.67	0.24	2.80	0.45	0.97	1.62	0.58	8.12	10.13	18.25	375,023	3.406
July.........	0.44	0.46	0.18	2.47	0.34	0.89	1.39	0.36	6.53	6.66	13.19	565,787	3.641
August.......	0.29	0.57	0.15	2.48	0.33	0.85	1.38	0.37	6.42	5.62	12.04	594,852	3.811
September....	0.37	0.54	0.21	2.71	0.39	0.85	1.42	0.42	6.91	7.34	14.25	487,543	3.771
October......	0.73	1.19	0.28	3.05	0.47	0.91	1.69	0.52	8.84	12.34	21.18	339,789	3.564
November....	1.40	2.45	0.47	3.71	0.51	0.96	1.71	0.54	11.75	10.58	22.33	311,882	3.379
December....	0.63	1.94	0.21	3.93	0.51	0.93	1.71	0.74	10.60	12.13	22.73	334,936	3.494
Avg.........	0.66	1.01	0.27	3.33	0.43	0.91	1.52	0.67	8.80	9.39	18.19	4,552,532	3.518

The total net output from the station is also shown as well as the pounds of coal per kw-hr. and the cost of coal per ton of 2,000 lb.

Table III is given showing the cost of maintenance of the transmission system, which includes high-tension transmission, overhead trolley, third rail and running track bonding.

In connection with the maintenance cost of overhead trolley, it should be borne in mind that the trolley construction is of

TABLE III

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE

Cost of maintenance of transmission systems
Year 1910

	High tension		Overhead trolley		Third rail		Running track bonding	
	Total	Per mile	Total	Per mile	Total	Per mile	Total	Per mile
January...	$142.96	$2.04	$690.84	$35.32	$492.96	$3.74	$26.67	$1.51
February..	409.74	5.85	266.38	13.62	580.80	4.41	562.82	3.75
March.....	198.62	2.84	381.28	19.49	495.55	3.76	39.26	0.26
April......	403.44	5.76	446.57	46.71	745.16	5.26	†30.24	0.20
May......	256.14	3.66	291.51	30.49	1,126.40	7.95	190.05	1.27
June......	123.21	1.76	864.62	90.44	957.42	6.75	312.08	2.08
July.......	167.90	2.40	393.62	41.17	818.29	5.77	494.79	3.30
August....	357.20	5.10	317.49	33.21	1,631.72	11.51	32.99	0.22
September.	508.51	7.26	389.73	40.77	838.87	5.92	202.05	1.35
October....	604.93	8.64	245.75	25.70	647.27	4.57	98.66	0.66
November.	171.58	2.45	363.35	38.01	1,062.98	7.50	189.83	1.26
December.	100.34	1.43	244.02	25.52	1,466.71	10.35	125.03	0.83
Total and avg. per mi. per mo....	$3,444.57	$4.10	$4,895.16	$36.70	$10,864.13	$6.46	$2,445.72	$1.36

†Credit for scrap 58.75

TABLE IV

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE

Cost of operation and maintenance of substations
Year 1910

	Total for eight substations				
	Operation	Maintenance	Total	Cost per kw-hr.	Substation output kw-hr. 675 volts direct-current
January......	$1,573.82	$373.10	$1,946.92	$0.001136	1,655,800
February.....	1,601.78	147.39	1,749.17	0.001157	1,460,200
March........	1,618.16	174.27	1,792.43	0.001035	1,678,400
April.........	1,728.98	275.64	2,004.62	0.001251	1,554,900
May.........	1,760.46	370.91	2,131.37	0.001267	1,635,900
June.........	1,794.44	432.55	2,226.99	0.001310	1,655,600
July..........	2,006.97	317.62	2,324.59	0.001047	2,175,700
August.......	1,751.03	194.13	1,945.16	0.000811	2,349,000
September....	1,776.14	903.45	2,679.59	0.001285	2,035,200
October.......	1,744.23	145.99	1,890.22	0.001069	1,712,100
November....	1,750.62	142.23	1,892.85	0.000986	1,860,100
December.....	1,745.68	130.02	1,875.70	0.000829	2,199,400
Year.........	$20,852.31	$3,607.30	$24,459.61	$0.001082	21,972,300

rigid span type and also that current is collected by a trolley wheel on each car of a train, the number of cars per train varying from two to seven, the average being about three.

Originally the ten mile line from Newfield to Millville was equipped with overhead trolley of the same construction as the present line. This trolley was replaced by third rail the latter part of March, 1910, hence the maintenance cost per mile in Table 3 is based on 19.55 miles to March, inclusive, and on 9.55 miles from that time on.

The operation and maintenance of substations for the year 1910 is shown in Table IV. This shows the cost of operation and maintenance of the eight substations during the year 1910, by month, as well as the cost per kw. hr. output per substation and the output in direct current at 675 volts.

DETENTIONS TO TRAIN SERVICE

A detailed statement of the detentions to electric train service occurring during the year 1909 is given in table No. VIII. The column headed " Number of detentions," means number of trains detained and is subdivided into totals and per cent of total. The column headed, " minutes detention ", shows the train minutes of detention for each cause and is subdivided into the headings of totals and per cent of totals. The column headed " car miles per minute of detention ", shows the total car miles per train minute of detention for each cause.

A further subdivision of the detentions due to train equipment shown under the general heading " motive power ", is given in Tables IX and X the first being for the year 1909 and the second for the year 1910. This statement shows the detentions that occurred during each year by months and it may be well to say that the figure shown above the line represents the number of detentions, while the figure below the line represents the train minutes delay for that particular detention.

RENEWAL OF PARTS OF CAR EQUIPMENT

The number of renewals of the various parts of car equipment for the year 1909 is given by months in Table V and the same information for the year 1910 is given in Table VI.

The car mileage for 1909 being 4,106,765 and for 1910, 4,552,056, it is seen that the number of car miles per third rail shoe replaced in 1909 was 8068 and in 1910 was 4079, giving an average of about 6005 car miles per replacement. As each car is

TABLE V

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE RENEWAL OF PARTS OF CAR EQUIPMENT 1909

Part of equipment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Third rail shoes replaced	42	38	51	42	12	10	39	59	28	71	62	55	509
Brake shoes replaced	388	237	353	423	304	435	536	592	689	476	402	462	5297
Trolley poles bent	3	1	14	8	9	12	12	15	10	10	3	11	108
Trolley poles broken	0	0	1	0	0	0	0	1	0	0	1	0	3
Trolley poles missing or replaced	0	1	0	0	0	0	0	0	0	0	4	0	5
Trolley wheels lost or replaced	24	23	25	19	27	2	36	17	38	13	11	24	259
Trolley retriever dogs broken	0	0	0	0	0	0	0	0	0	0	0	0	0
Trolley harps broken or replaced	11	7	5	2	5	3	6	6	5	1	0	0	51
800 ampere shoe fuses blown	264	198	226	193	180	113	101	125	69	138	197	279	2081
800 ampere trolley fuses blown	52	33	34	40	15	26	45	101	37	53	46	36	518
800 ampere bus fuses blown	15	10	17	9	11	6	17	14	11	21	12	59	202
25 ampere controller fuses blown	5	7	6	6	2	0	0	1	2	6	5	11	51
20 ampere No. 2 heater fuses blown	15	18	9	24	4	7	0	0	2	23	16	26	144
10 ampere No. 1 heater and comp. fuses blown	21	27	25	18	7	2	1	9	24	28	27	35	224
5 ampere cab heater fuses blown	0	1	0	0	0	0	0	0	1	0	0	4	6
4 ampere control cable fuses blown	3	4	11	1	0	1	1	2	7	1	1	2	34
2 ampere headlight fuses blown	4	0	1	3	2	0	2	3	5	1	0	13	34
1 ampere car light fuses blown	2	1	0	4	9	6	5	8	19	7	3	11	75
50 c.p. headlights burned out	20	18	10	18	11	22	40	40	36	24	16	16	271
50 c.p. headlights missing	1	1	1	3	1	4	1	0	3	1	0	1	17
16 c.p. lamps burned out	188	148	180	182	140	103	129	153	163	141	156	169	1862
16 c.p. lamps missing	41	45	42	14	42	26	15	21	33	18	28	51	376
16 c.p. lamps broken	9	18	4	18	5	22	6	7	6	9	7	14	125
Gauge lamps replaced	24	18	14	10	12	5	4	12	4	5	11	10	129

TABLE VI

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
RENEWAL OF PARTS OF CAR EQUIPMENT
1910

Parts of equipment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Third rail shoes replaced	198	125	157	43	27	58	26	41	67	54	73	60	933
Brake shoes replaced	425	454	511	469	511	570	675	780	531	416	444	514	6300
Trolley poles bent	4	6	12	12	5	9	8	12	16	2	1	2	89
Trolley poles broken	3	3	1	3	1	0	3	0	3	1	0	0	18
Trolley poles missing or replaced	2	4	0	1	0	1	1	4	3	1	0	4	21
Trolley wheels lost or replaced	19	2	13	9	10	19	18	5	13	3	1	12	124
Trolley retriever dogs broken	0	0	0	0	0	0	0	0	0	0	0	0	0
Trolley harps broken or replaced	2	4	1	4	0	4	2	1	3	2	0	2	24
800 ampere shoe fuses blown	186	199	284	173	178	248	229	304	287	210	197	303	2798
800 ampere trolley fuses blown	56	55	51	23	22	48	107	75	70	32	17	19	575
800 ampere bus fuses blown	48	11	25	29	17	29	19	22	22	6	3	17	248
25 ampere controller fuses blown	14	8	4	6	1	2	4	0	0	1	20	5	65
20 ampere No. 2 heater fuses blown	17	13	19	7	0	2	0	0	0	2	33	13	106
10 ampere No. 1 heater and comp. fuses blown	28	31	21	19	7	9	2	1	3	5	27	25	178
5 ampere cab heater fuses blown	0	14	0	0	0	0	0	0	0	0	0	1	15
4 ampere contrl. cable fuses blown	0	0	2	0	0	1	6	5	6	2	4	3	29
2 ampere headlight fuses blown	9	24	4	6	3	2	1	1	7	5	3	17	82
1 ampere car light fuses blown	4	16	21	3	3	6	2	2	6	3	3	7	76
50 c.p. headlights burned out	25	14	3	18	16	14	21	13	18	14	12	9	177
50 c.p. headlights missing	17	21	1	3	2	3	3	2	6	0	0	6	64
16 c.p. lamps burned out	193	211	159	125	93	76	96	109	135	163	157	182	1699
16 c.p. lamps missing	72	59	64	50	49	45	25	26	27	39	54	67	577
16 c.p. lamps broken	19	20	7	6	0	2	5	4	9	5	3	3	83
Gauge lamps replaced	27	17	6	13	9	8	10	8	7	1	4	0	110

equipped with four shoes this gives an average life of 24,020 miles per shoe.

Likewise the number of car miles per brake shoe was 775 in 1909 and 722 in 1910 or an average of about 747 car miles per replacement. The average life of each brake shoe is therefore about 5976 miles.

The number of replacements of the remaining items is governed rather by special occurrences than by mileage, with the exception of the lamps, the average life of which is not readily obtainable owing to incomplete data concerning number of hours burned.

A statement is also included showing the breakage of gears and pinions by month for the years 1909 and 1910. This will be found by reference to Table VII.

TABLE VII

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE

Gear and pinion breakages

	1909	1910
January	4	1
February	3	1
March	5	3
April	2	1
May	1	5
June	0	1
July	0	0
August	1	0
September	1	0
October	2	0
November	0	0
December	2	1
Total	21	13

Table XI shows, by months, for the years 1907, 1908, 1909 and 1910 certain general power data, which are included as being of some interest. This statement, shows the kw-hr. output from power station, the cost in mills per kw-hr. output, pounds of coal per kw-hr., and the efficiency of transmission and conversion from the alternating current bus in the power station to direct current bus in substations.

An improvement will be noted in the reduction of cost of power, as well as a reduction in coal consumption per kilowatt hour. The most marked improvement, however, will be noted in efficiency of transmission and conversion, which is accounted for by the fact that the operation of the substations is followed up with care so as to minimize the idle operation of rotaries.

TABLE VIII
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
Detentions

Year 1909

Causes	Train detentions, number, time and per cent for various causes				
	Number of detentions		Minutes detention		
	Total	Per cent of total	Total	Per cent of total	Car miles per minute detention
Transportation.					
Boat connection	51	0.553	180	0.403	22,815.36
Baggage, express and mail	1898	20.575	8373	18.749	490.47
Heavy travel	1232	13.355	4612	10.328	890.45
Collecting tickets	72	0.781	334	0.748	12,295.70
Train connections	977	10.591	5517	12.354	744.38
Traffic ahead	1723	18.677	7842	17.561	523.68
Held at signal	1390	15.068	4767	10.675	861.50
Stops on order	73	0.791	165	0.369	24,889.49
Fast schedule	34	0.368	57	0.128	72,048.50
Picking up and cutting off cars	411	4.455	1312	2.938	3,130.15
Fog	41	0.444	127	0.284	32,336.73
Signal failure	208	2.255	860	1.926	4,775.31
Accidents	26	0.282	261	0.584	15,734.73
Obstructions	33	0.358	194	0.434	21,168.89
Miscellaneous	283	3.068	1427	3.196	2,877.90
Total transportation	4852	91.621	36028	80.677	113.98
Motive power.					
Power house trouble	15	0.163	69	0.155	59,518.30
High tension line trouble	14	0.152	81	0.181	50,700.80
Lightning	12	0.130	47	0.105	87,377.90
Overloads in substations	11	0.119	61	0.137	67,324.00
Third rail shorts	3	0.032	14	0.031	293,340.40
Third rail out of place	1	0.011	8	0.019	513,345.13
Third rail anchor on fire	1	0.011	5	0.011	821,353.00
Third rail protection out of place	1	0.011	1	0.002	4,106,765.00
Trolley wire trouble	253	2.742	1920	4.299	2,138.94
Train equipment	237	2.569	1568	3.511	2,619.11
Total motive power	548	5.940	3774	8.451	1,088.17
Weather Conditions.					
Snow, head winds, wet rail	178	1.929	4043	9.054	1,015.77
Sleet on third rail	47	0.510	812	1.818	5,057.59
Total weather condition	225	2.439	4855	10.872	845.88
Grand total	9225	100.00	44657	100.00	91.96

Total car mileage	4,106,765
Car miles per detention	445.18
Car miles per minute of detention	91.96

TABLE XI
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
General power data

	1907				1908			
	Alternating Current kw-hr Power Station Output	Cost in Mills per Kw-hr. Output	Lb. of Coal Kw-hr. Output	Efficiency Power Sta. Bus to Substation Bus	Alternating Current Kw-hr. Power Station Output	Cost in Mills per Kw-hr. Output	Lb. of Coal Kw-hr. Output	Efficiency Power Sta. Bus to Substation Bus
January......	1,911,600	8.83	3.91	72.6	2,009,600	6.10	3.49	73.3
February.....	1,691,500	7.95	3.63	74.5	1,913,100	6.35	3.55	73.6
March........	1,583,000	7.76	3.96	71.5	1,873,300	6.17	3.46	72 3
April.........	1,464,300	7.43	3.95	74.0	1,836,200	5.86	3.45	71.8
May.........	1,400,400	6.81	3.53	72.1	1,744,900	6.06	3.40	69.6
June.........	1,395,700	7.65	3.98	70.6	1,707,500	5.91	3.52	74.8
July.........	1,938,100	6.05	3.65	71.6	2,104,300	5.43	3.37	75.6
August.......	2,082,000	6.00	3.43	71.6	2,268,000	5.43	3.18	75.8
September...	1,855,300	6.07	3.46	71.7	1,849,200	5 76	3.18	74.7
October......	1,849,800	5.99	3.53	82.8	1,786,700	5.78	3.25	72.8
November....	1,893,600	5.86	3.51	71.3	1,802,000	5.78	3.35	74.7
December....	2,053,600	6.00	3.51	72.5	1,993,000	5.80	3.25	76.2
Av. for year..	1,759,900	6.80	3.67	72.2	1,907,300	5.92	3.37	73.8
	1909				1910			
January......	1,959,700	5.67	3.23	76.1	2,131,000	5.15	3.31	81.8
February.....	1,756,500	5.71	3.25	76.1	1,865,300	5.73	3.46	82.4
March.......	1,903,600	6.04	3.33	76.1	2,168,600	5.42	3.27	81.3
April.........	1,869,300	5.90	3.27	75.0	2,031,400	5.62	3.22	80.1
May.........	1,788,800	5.65	3.26	75.5	2,115,900	5.25	3.27	79.5
June.........	1,749,200	5.77	3.22	77.7	2,167,500	5.68	3.14	80.3
July.........	2,426,000	5.21	3.25	78.0	2,784,300	5.88	3.16	82.5
August.......	2,324,400	5.27	3.34	81.5	3,088,300	5.11	3.06	80.7
September....	2,056,100	5.28	3.34	80.3	2,590,400	5.17	3.31	82.9
October......	1,836,600	5.40	3.27	80.1	2,229,000	5.48	3.17	80.8
November....	1,869,500	5.49	3.41	80.7	2,381,500	5.19	3.29	81.9
December....	2,154,800	5.42	3.41	81.0	2,759,300	5.31	3.39	83.4
Av. for year..	1,962,600	5.55	3.30	78.4	2,359,400	5.42	3.25	81.6

A paper presented at the 260th Meeting of the American Institute of Electrical Engineers, Toronto, Can., April 7, 1911, and discussed at the 28th Annual Convention, Chicago, June 28, 1911.

ELECTRIFICATION ANALYZED, AND ITS PRACTICAL APPLICATION TO TRUNK LINE ROADS, INCLUSIVE OF FREIGHT AND PASSENGER OPERATION

BY WILLIAM S. MURRAY

Succinctly, the object of this paper is to place before the practical engineer and railroad man the facts concerning *trunk line electrification*, and bring home to him the simple truth that it can be treated in a class of its own; practically no exceptions existing therefrom. I would recommend that we be wary of the old expression so often repeated—" Every situation is a study in itself ", and see if we cannot recognize a standard that will apply to all. In this connection I venture the opinion that there is no trunk line situation that exists to-day, but what there is a construction drawing in the New Haven engineering files that would have immediate application. No one can extract any individual credit for this fact; it is entirely due to the system itself, as it possesses the required elements of simplicity and flexibility. The religion of this paper is to preach the doctrine of universal use of single-phase current on trunk line roads inclusive of suburban and terminal territory, as applied to freight and passenger operation, and I offer for consideration the standardization of 11,000 volts on the contact wire and a system frequency of 25 cycles. In suggesting 11,000 volts on the contact wire, this is advocated for application on railroad right-of-way which may be adjacent to foreign road territory to permit of one company's equipment operating upon the right-of-way of another. This voltage is recommended as a minimum potential; it being recognized that there is no objection to a higher voltage on other lines individual to themselves where transmission economy can be obtained by the use of the higher voltage.

In recommending 25 cycles as standard for single-phase electrification, this is not so much based upon the successful use of this frequency on the New Haven road, as upon my belief that the future will undoubtedly see single-phase locomotive induction motors and probably single-phase current received at the terminals of the locomotive and transformed into direct current without the use of any rotating element within the locomotive. If 15 cycles, as some have been prone to recommend of late years, be elected as a standard frequency, such a frequency would handicap, if not eliminate, the opportunity of obtaining one of these two highly desirable alternatives entirely within reach by the use of 25 cycles.

We have made electrification in its various forms work. We can now make it pay. The only possible way that electrification can be made to pay is by electing such a system, the yearly operating cost of which, inclusive of its maintenance charges, subtracted from the yearly cost of the steam system it replaces, leaves a figure which represents a little more than the interest on the capital investment required for the installation of the electrical system. When the board of directors of a railroad company pass favorably upon an appropriation of several millions of dollars to purchase power houses at, say, a million dollars apiece, locomotives at $30,000 apiece and line construction at $25,000 or $30,000 a mile for a four-track system, it is not an unfair question for that board of directors (who, while they may be interested in eliminating the smoke and dirt incident to the original system replaced, and be glad to have the assurance of the electrical engineer that the time of switching movement of the railroad's equipments both in yards, terminal property and main line have been reduced) to ask for a closer analysis than this, and also ask for some specific explanation as to the return each year of a percentage of some of the dollars spent.

In the generosity of his heart, the practical railroad man has looked with some commiseration, some kindness and lately with some real interest upon those electrical engineers who are truly endeavoring, while engrossed in the principles of their own electrical art, not to forget in their studies to take into consideration the principles now of such long standing that have placed the art of steam railroading on its present sound basis.

With that in mind there follows in this paper a series of studies of a steam locomotive as it appears in its four classes, on a typical trunk line property. The whole problem of electrification, if viewed from the point of whether it is to pay, settles down to how much it costs to produce the necessary tractive effort required in

1. The passenger express locomotive;
2. The passenger local locomotive;
3. The freight road engine;
4. The freight switch engine;

together with such other costs incident to the electrical system.

The writer, during the past four years, has had the opportunity of studying these four classes of steam locomotives. The old railroad man when he reads over these statistical records will recognize the results. The electrical man, after he has read them, must realize that to make his electrification pay he must be able to reproduce the four classes of steam tractive efforts by electricity, with a total investment, the interest on which must be carried by the economies to be effected over steam operation.

THE STEAM PASSENGER LOCOMOTIVE

In a discussion of the paper presented before the American Institute of Electrical Engineers by Messrs. Stillwell and Putnam on January 25, 1907, the writer presented a tabulated set of figures with reference to the fuel required for the operation of steam passenger and freight locomotives, and the yearly cost of their maintenance and repairs.

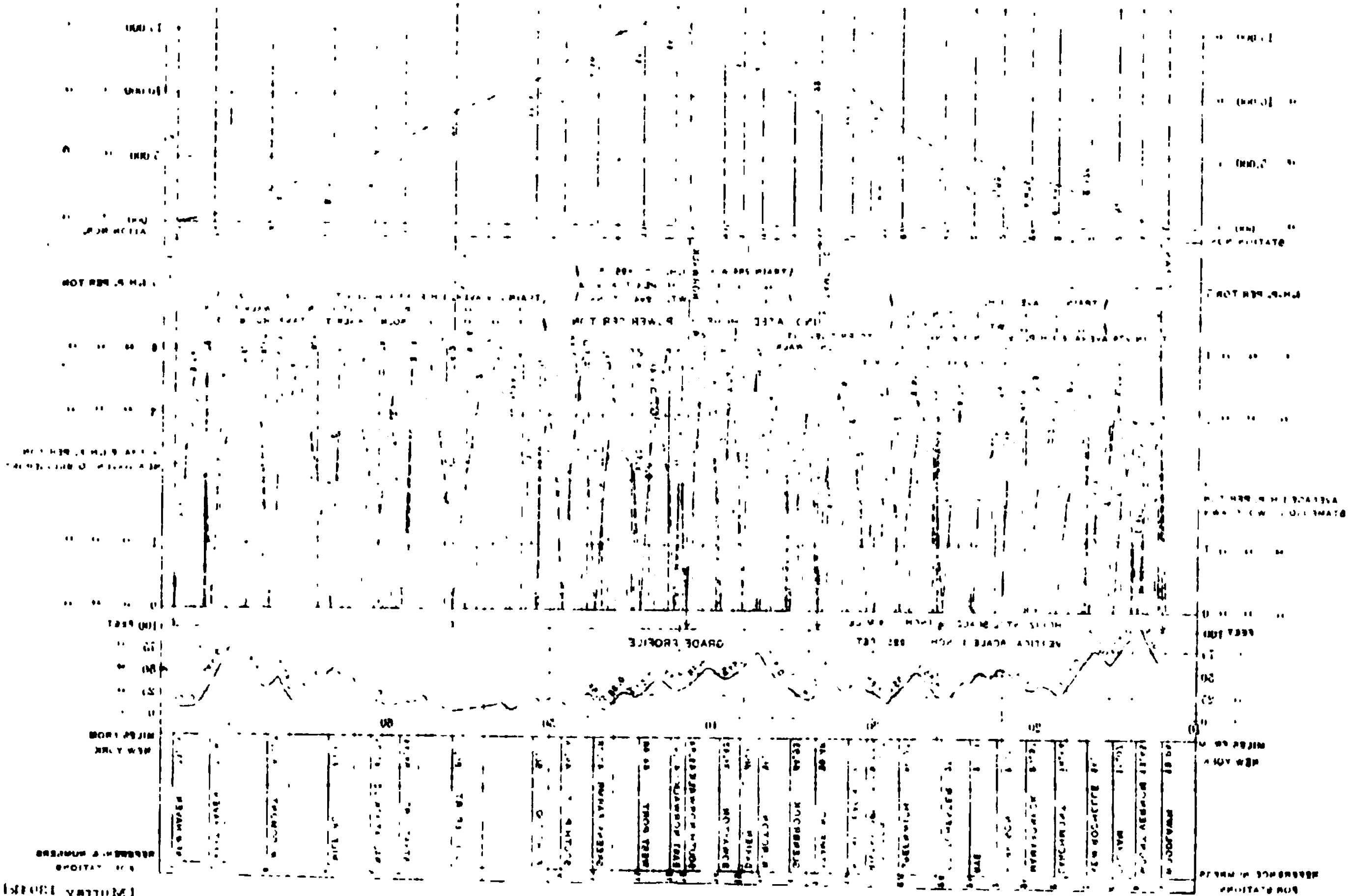
Briefly quoting from that discussion, TRANSACTIONS A.I.E.E., Vol. XXVI, page 146, and with reference to the tables 1 and 2 there presented, showing the relation between coal consumption and ton-miles, the following statement is made: " An interesting and valuable query is—What fraction of a pound of coal is consumed in producing a ton-mile in any one of the above services? Tables 2 and 3, following, show that it takes 0.169 lb. of coal, 0.194 lb. of coal and 0.335 lb. of coal to produce a ton-mile in freight, express passenger and express local passenger service, respectively." In an effort to condense as much as possible the discussion, and confine the remarks to the results obtained, the writer omitted the presentation of the actual data from which the results were obtained; having in mind that later, and at a more opportune time, this data would be of interest. A very fair express and local trunk line service is offered in the trains of these respective classes between New Haven and New York City; and, as explained in the discussion previously referred to, a month was devoted to the study of the capacity of engines required and the coal consumed in such services over the 61.5 miles of route between New Haven and Woodlawn, N. Y., (east and west runs). In Figs. 1, 2, 3, 4 and 5, herewith, is given information with reference to average cut-off, boiler pressure, water consumption, indicated horse power and grade—all referred to stations along the route and supplemented by a synopsis of the general engine and train conditions which are inclusive of train schedule, weights, cylinder and wheel sizes, etc.

These data were secured for express operation, and the manner in which the tests were conducted is covered in TRANSACTIONS A.I.E.E., Vol. XXVI, page 146.

Figs. 6, 7, 8, 9 and 10, following, cover similar data for the steam local operation between New Haven and Woodlawn (east and west runs).

Figs. 11 and 12 give the respective averages of the aforegoing five tests, each for the express and local operation. The ten runs are presented, first, as a record of individual runs, and second, to show how very closely the tests checked upon themselves. As Figs. 11 and 12 are the summation and average of all other tests, the results plotted thereon can be used as references, rather than any data on Figs. 1 to 10, inclusive.

Space required for other matters does not permit a generous amount of discussion of these steam locomotive statistics. They present, perhaps, some reassuring evidence of our effort to become intimately acquainted with the problem the steam engineer had solved before the electrical engineer assimilated it for betterment. The writer would have liked to have covered the investigation more completely by a more exhaustive study of the track resistance, using trains of varying weight. Time, however, in those days was ever the essence of the contract, and the writer knew that the choice of train weights slightly below the average conditions would bring constants for ton-mile energy consumption at rates higher, and thus safer for reference in settling electrical capacities; and also knew that the future would offer a better opportunity to study the resistance problem by electric rather than steam locomotives. The two data most interesting to the writer in these plotted charts is the indication of the size of locomotive required to accomplish the



[Murray [illegible]]

FIG. 12.—Steam local suburban runs

Train 279 A

[illegible]

Schedule time, 2 hours, 32 mins., New Haven to Woodlawn.

Average time, 2 hours, 42 mins., New Haven to Woodlawn.

Schedule time, 34 mins., New Haven to B'port.

Actual time, 30 min., 39 sec., New Haven to Bridgeport.

[illegible]

Actual time, [illegible] mins., [illegible] sec., So. Norwalk to Stamford.

Schedule time, [illegible] min., Stamford to Woodlawn.

Actual time, [illegible] mins., 15 sec., Stamford to Woodlawn.

Average wt., New Haven to B'port, 268.85 tons.

Average wt., B'port to So. Norwalk, 257.15 tons.

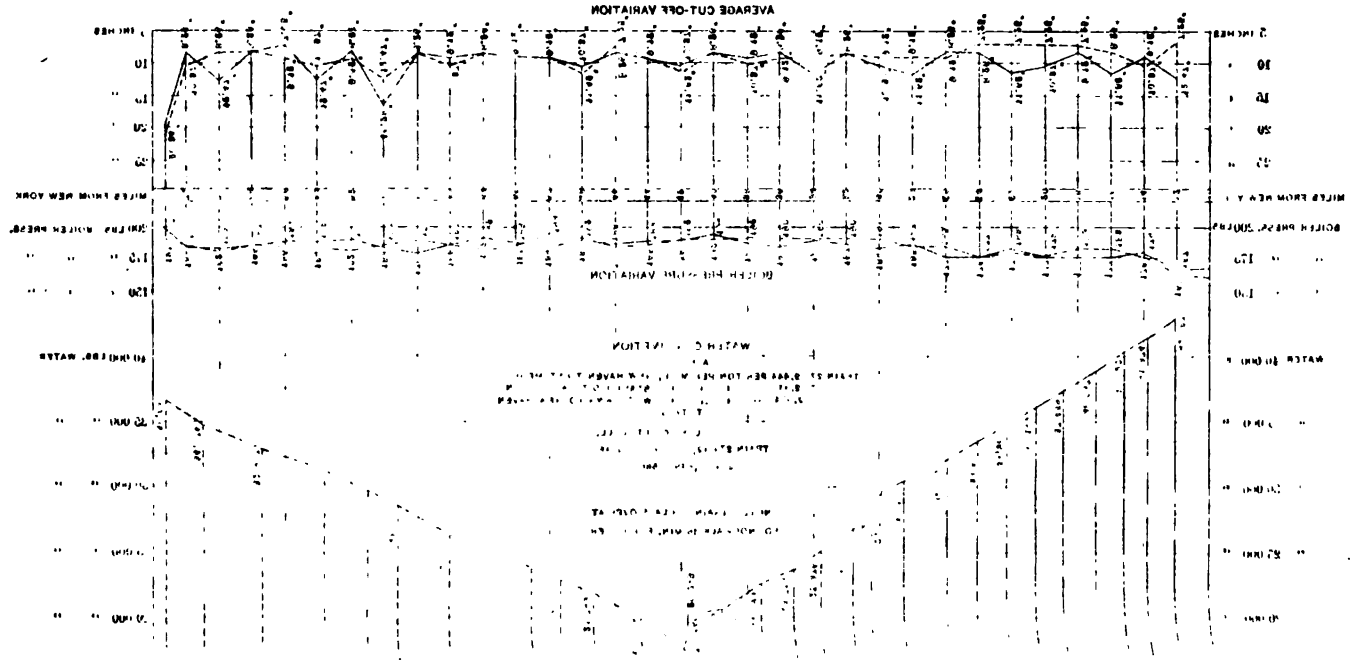
Average wt., So. Norwalk to Stamford, 262.75 tons

Train 284 Average.

[illegible]

Synopsis

Engine 1910.
Size cylinder 20"x26".
Size wheel [illegible]
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender, 232,000 lb.
Type, American.
Tank capacity, 5,500 gallons.



express and local schedule between New Haven and New York. The horse power per ton of train movement immediately afforded a check on the capacity of the engine required, showing the normal size of unit to be elected, which, under an arrangement of multiple unit control, permitted the proper amount of engine power to apply to trains of varying weight; the other data most interesting and important to the writer was the water consumption, giving a close check on the relative energy requirements between express and local service. This analysis of the steam engine under operation for trunk line conditions incident to the New Haven Road, caused us to choose for our passenger unit a locomotive, the normal capacity of which was 1000 h.p. at the rim of the locomotive wheels, and this size in practice has borne out our estimate of the capacity required. It may, therefore, be said that for trunk line conditions of the character that obtain on the New Haven Road, a locomotive unit capable of multiple unit operation and of 1000 h.p. continuous capacity, is the proper selection of unit size.

THE STEAM FREIGHT LOCOMOTIVE

Studying the freight engine requirements of a trunk line, from a steam locomotive point of view, I had conducted a series of tests on typical freight (or road) engines, the runs being over a distance of 55½ miles, and in this case trains in the regular log of the New Haven operation, varying in weights between 720 and 1500 tons, including weight of engine, were used.

Figs. 13, 14, 15 and 16 show east and west operation of trains in the vicinity of 1000 tons, and typify the average runs of trains; these figures show cut-off, boiler pressure, speed and miles per hour, indicated horse power—besides giving other data with reference to the class of engine, size of cylinders, weights, etc.

Table 1 shows the summation of ten tests, giving grand averages for the ten runs.

It is interesting to note in these figures that the average evaporation of water per pound of coal is 6.9; also to note in the runs indicated on Fig. 13 to 16, inclusive, that the average indicated horse power varies from 655 minimum to 892 maximum; the average speed varying from 23.5 miles per hour minimum to 31.5 miles per hour maximum.

The electrical locomotive we have designed to handle our general class of freight service, or what could be correctly called our electric freight road engine, has a normal horse power rating of

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train—O-B-2.
Date, 7-5-10.
Number of loaded cars 40—40 cars N. H. to Saybrook.
Total number of cars, 40 (39 cars Saybrook to N. L.; 38 cars N. L. to Midway.)
Weight of train, including engine, tender and caboose, (1468 N. H. to Saybrook; 1424 Saybrook to N. L.; 1400 N. L. to Midway).

Engine 457 Mogul type.
Cylinders 20″x28″—63″ drivers.
Boiler pressure, 200 lb.
Weight on drivers 131600 lb.
Weight of engine, tender and caboose, 140 tons.

Train—M-O-1.
Date, 7-1-10.
Number of loaded, cars 8.
Total number of cars, 51.
Weight of train, including engine, tender and caboose, 1091 tons.

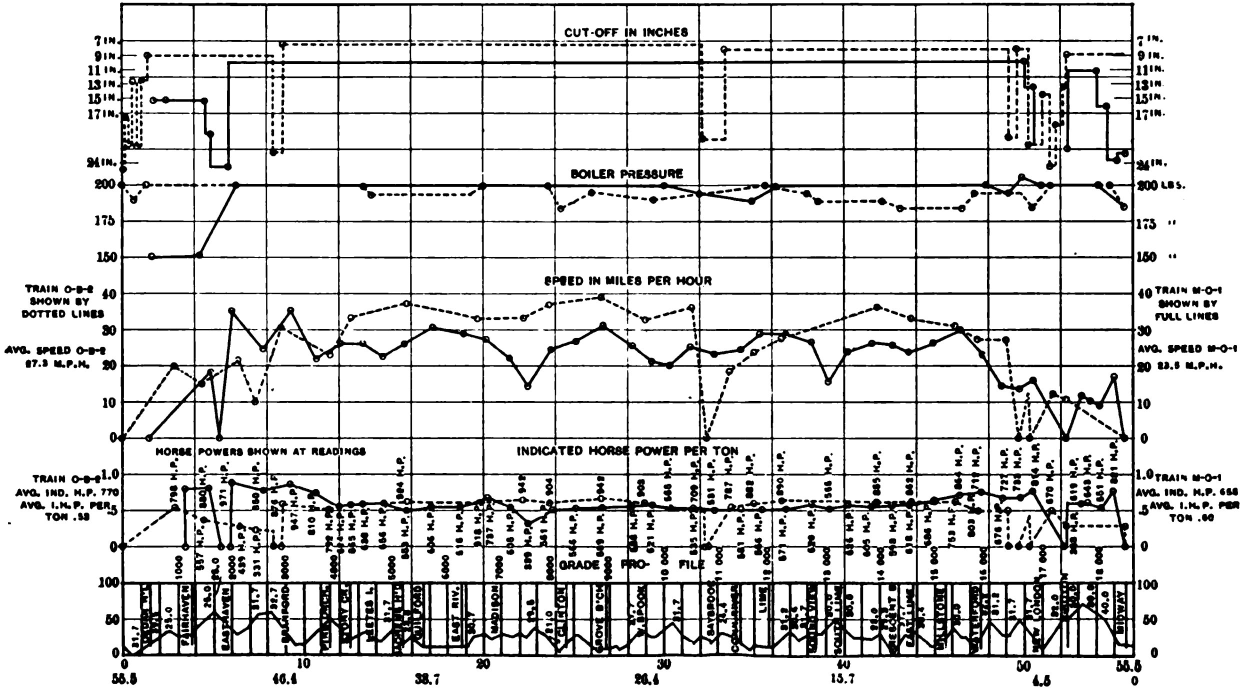


FIG. 13.—Steam freight runs

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train—O-B-2.
Date, 7-7-10.
Number of loaded cars 36 (36 New Haven to New London.
Total number of cars 36 (35 New London to Midway).
Weight of train, including engine, tender and caboose, (1357 N. H. to N. London; 1333 N. L. to Midway).

Engine 457. Mogul type.
Cylinders 20″x28″. 63″ drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender and caboose, 140 tons.

Train—M-O-1.
Date, 7-7-10.
Number of loaded cars, 8.
Total number of cars, 46.
Weight of train including engine, tender and caboose, 1105 tons.

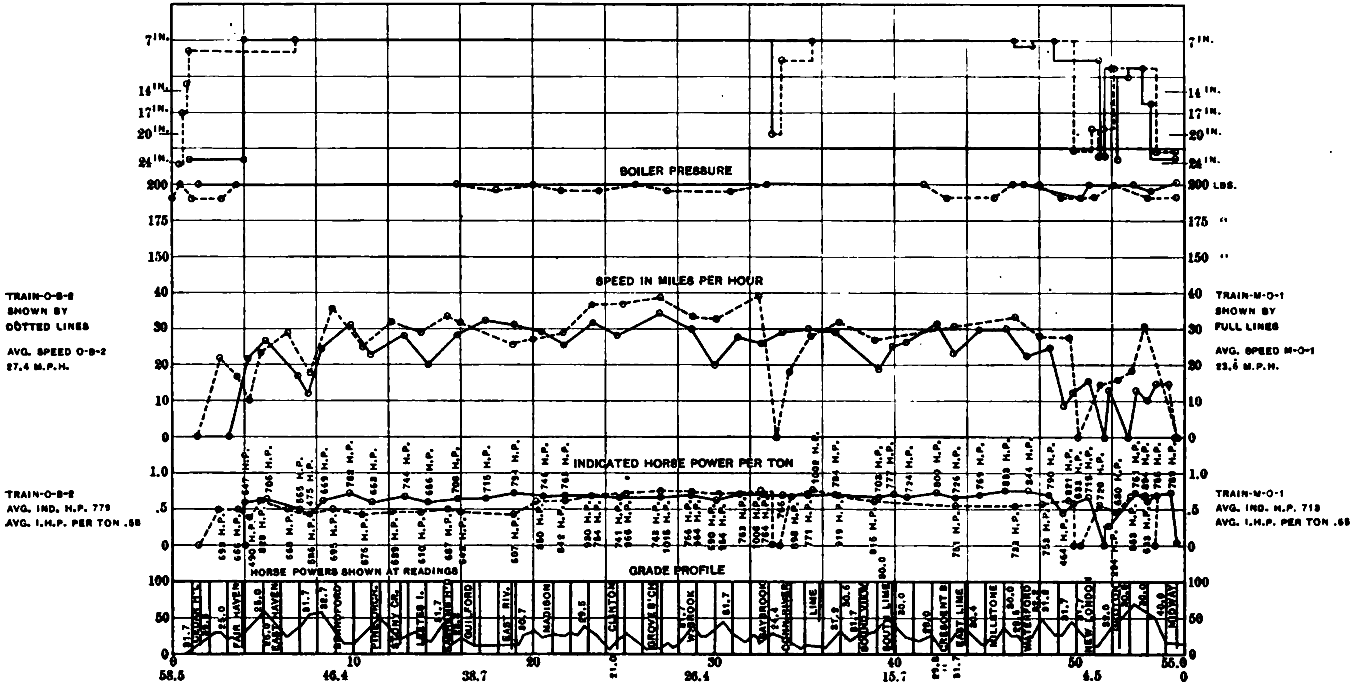


FIG. 14.—Steam freight runs

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train, O-B-2.
Date, 7-8-10.
Number of loaded cars, 41.
Total number of cars, 41.
Weight of train including engine, tender and caboose, 1526 tons.

Engine 457. Mogul type.
Cylinders 20"x28". 63" drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender and caboose, 140 tons.

Train, M-O-1.
Date, 7-8-10.
Number of loaded cars, 8.
Total number of cars, 45.
Weight of train including engine, tender and caboose, 991 tons.

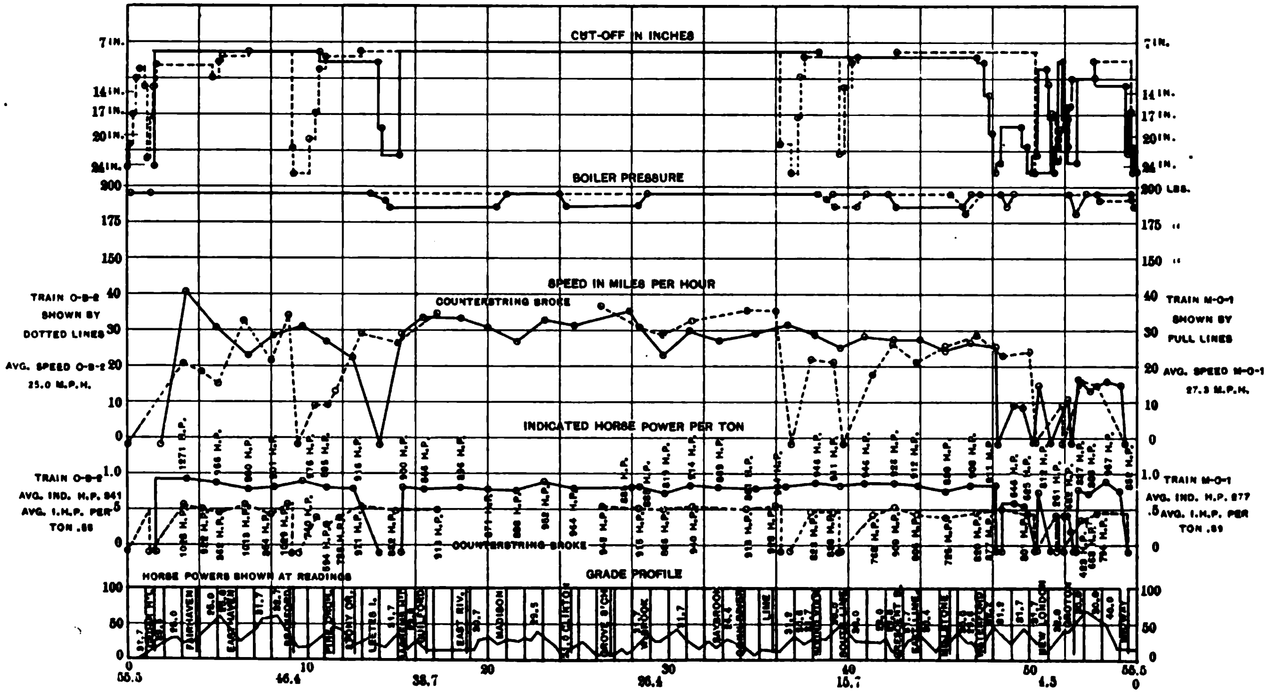


FIG. 15.—Steam freight runs

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train, O-B-2.
Date, 7-9-10.
Number of loaded cars, 37.
Total number of cars, 37.
Weight of train, including engine, tender and caboose, 1314 tons.

Engine 457. Mogul type.
Cylinders 20"x28". 63" drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender, and caboose, 140 tons.

Train, M-O-1.
Date, 7-9-10.
Number of loaded cars, 13 N. H., 14 N. L.
Total number of cars, 37 N .H., 38 N. L.
Weight of train including engine, tender and caboose, 966 m.-N. L., 922 N. L.-N. H.

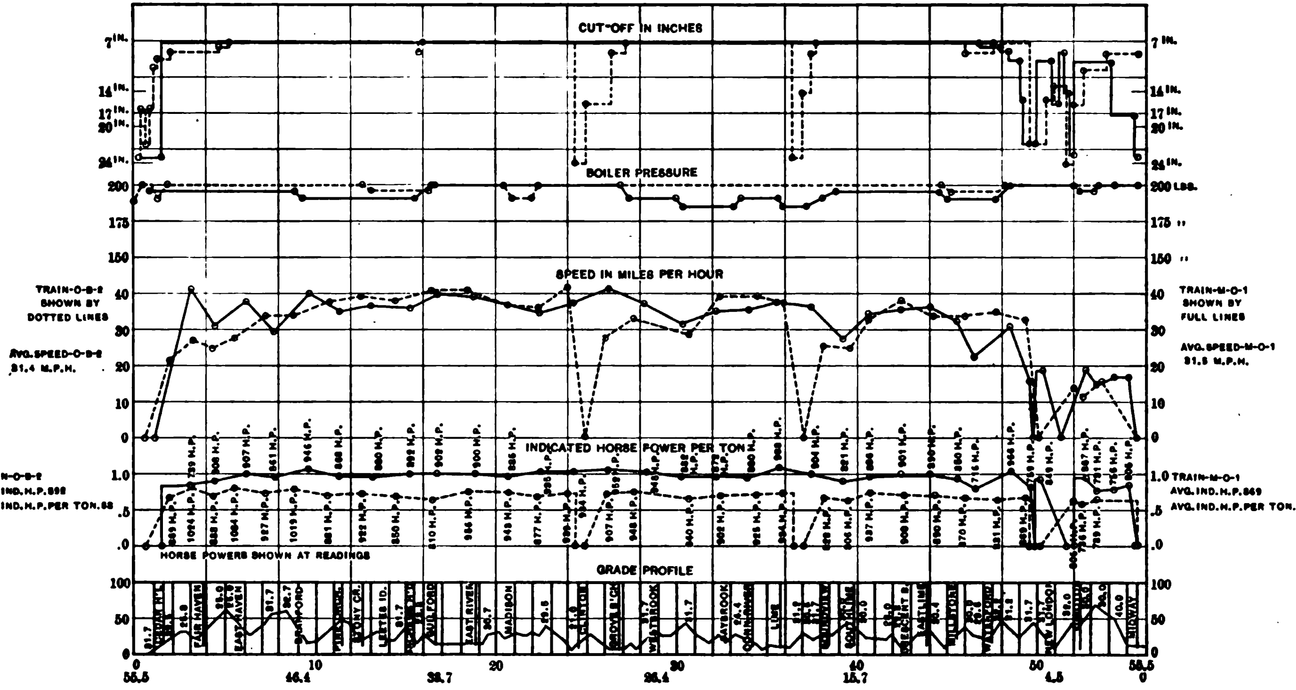


FIG. 16.—Steam freight runs

approximately 1400 h.p. This capacity provides a margin above the requirements indicated in the recorded tests as shown in Figs. 13, 14, 15 and 16. The excess capacity, however, is highly desirable in virtue of it affording the electric locomotive an opportunity to operate heavier trains and at a higher schedule speed than the steam locomotive it replaces.

Fig. 17 shows the motor characteristics of our electric road freight engine 071, and Fig. 18 is a record of tests made on locomotive 071 operating on N. Y. N. H. & H. rails between Stamford and New Rochelle, hauling a dead steam locomotive with thirty-seven freight cars and caboose—the total weight of train being 1438 tons. It is to be noted that data on this test is inclusive of voltage applied to motors, amperes, total kilowatts and speed.

25 cycle railway motor.
300 volts, 1000 amperes.
Continuous capacity 300 volts, 930 amperes.
Gear ratio 34:79 (1¾ D. P.) wheels 63".
Forced ventilation.

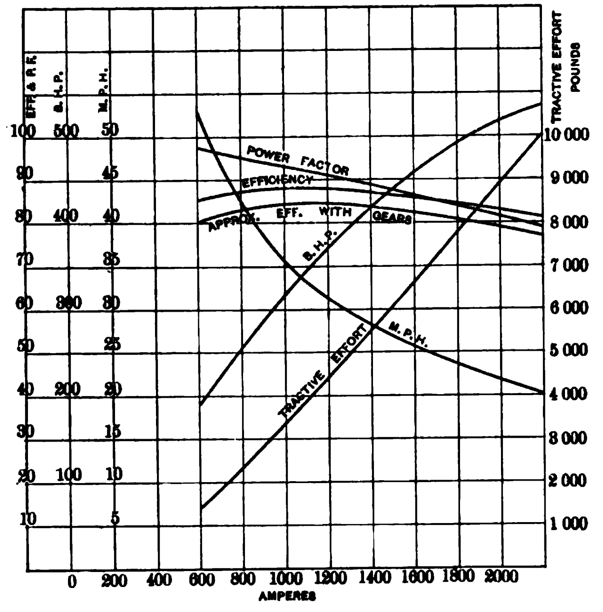


FIG. 17.—Speed torque characteristics of one of the motors of Locomotive No. "071"

It is of interest to note that the average speed over a distance of 1675 miles was 36.5 miles an hour; the average kilowatt input

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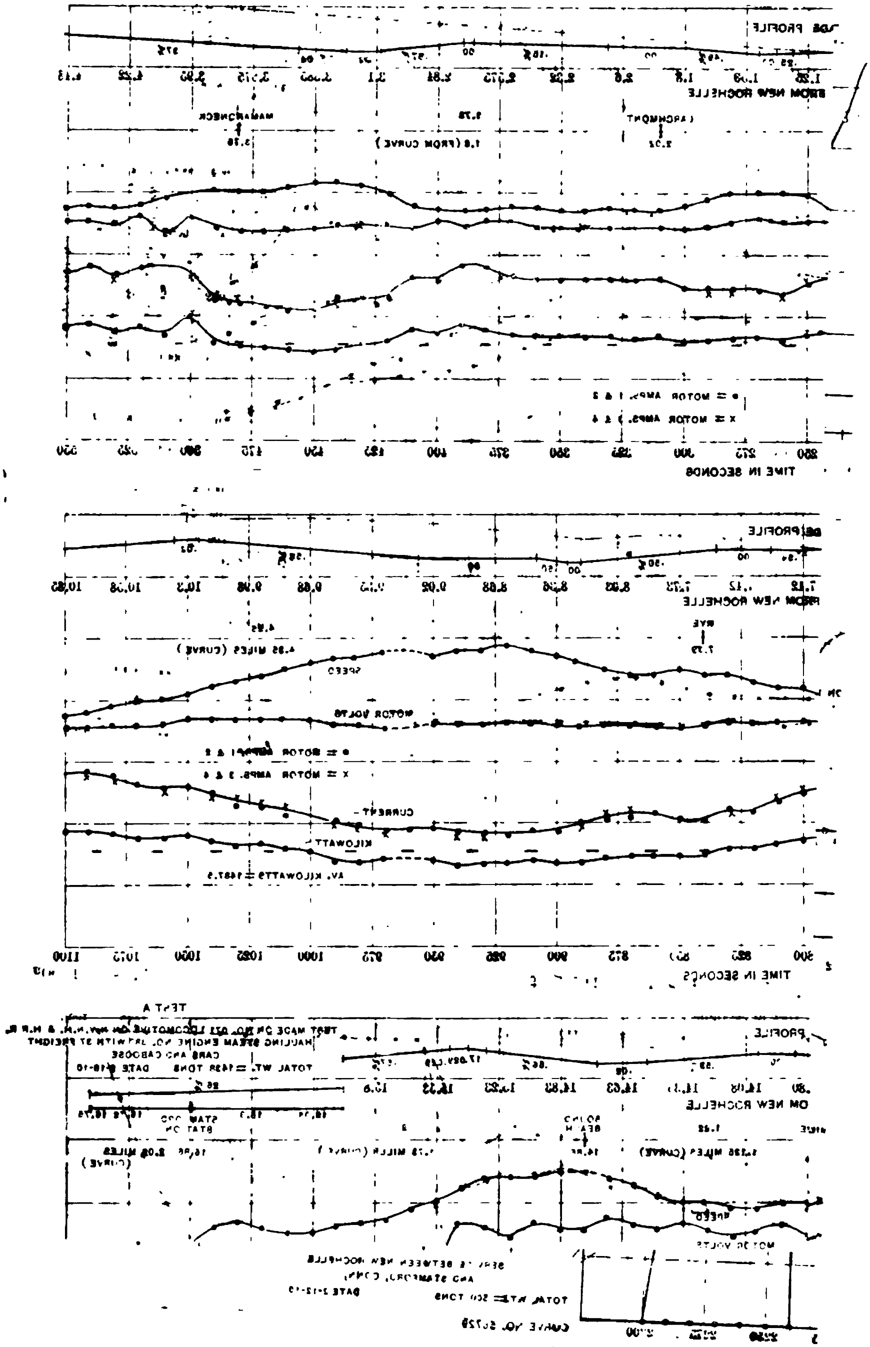
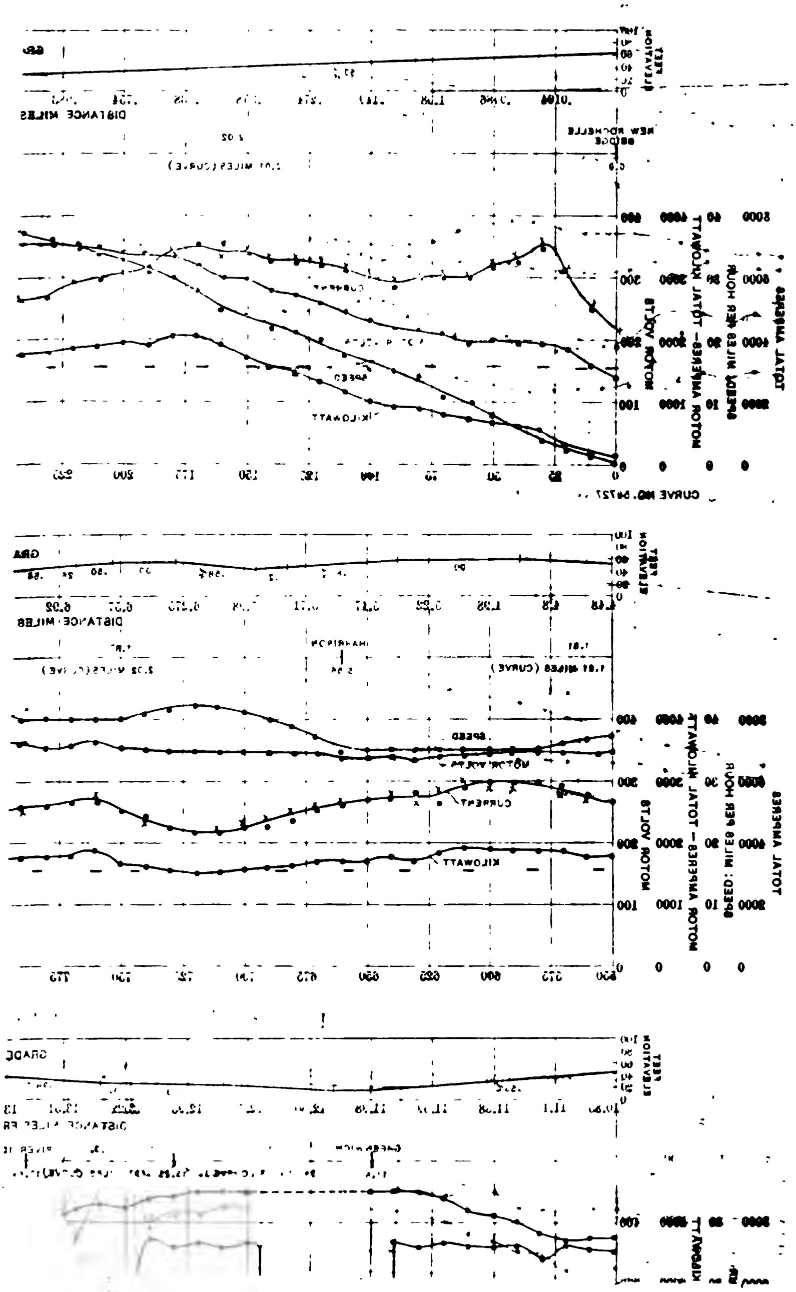


100 tons [illegible] (Murray 1400b)



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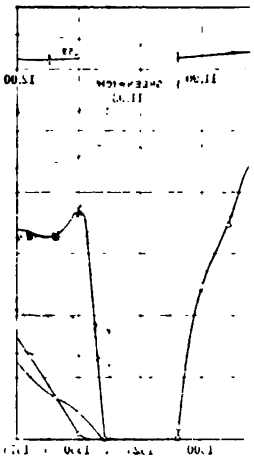

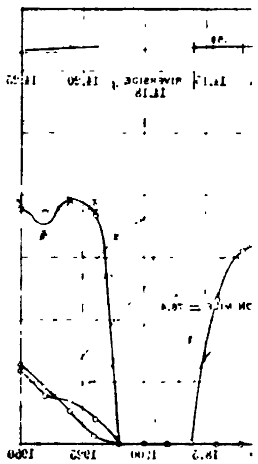

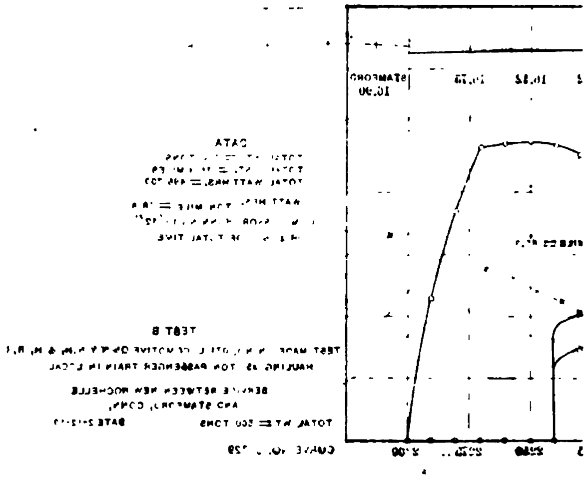

being 1,487 kw. with an average rim horse power at the drivers of 1650 h.p., and notwithstanding the locomotive was dragging a dead engine throughout this run, it accomplished the work at an average energy rate of 25.9 watt-hours per ton-mile.

Not uninteresting is the flexibility offered by the electric over a steam locomotive, in noting that its limitation of service is not absolutely confined to one class. Fig. 19 is a record of the same locomotive (071) making a local schedule in passenger service handling a total train weight of 500 tons; and notwithstanding the high ratio of the time of acceleration to total time of schedule, it is to be noted that the watt-hours per ton-mile were under 60.

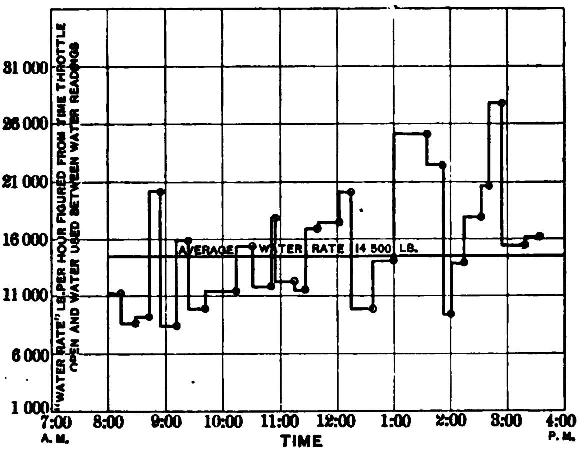
Test No. 1-A
Harlem River Yard, April 8, 1910.
Water used, 38,600 lb.
Anthracite coal used, 5540 lb.
Apparent evaporation, 6.98 lb.

FIG. 20.—Water and coal consumption on switch engine

THE STEAM LOCOMOTIVE SWITCHER

By far the most interesting investigation of the four types of steam engines employed in trunk line service was that of the steam switching locomotive, and a careful insight into its daily work revealed characteristics most surprising to the writer. In the many yards of the New Haven lines none afforded a better opportunity to study this type of engine than at Harlem River, where the duty imposed upon the switching locomotive, beside that of classification, included also float work, calling into account the necessity of heavy drafts of power and sustained for periods longer than usual to other switching yards; but even with this additional duty to perform, the relatively small amount of energy required for this work yielded, as before stated, a great surprise. From April 8th to April 29th, 1910 inclusive, careful observations for twelve days of switching movements were made on our switch engine 2,392; nine days of which were in the Harlem River yard and three in the Oak Point yard. The log sheets of tests include reading of water meters taken at frequent intervals, average boiler pressure, time throttle open, time engine in motion or standing, total cars handled, notation of loads and empties. Space permitting, complete detail data sheets of the twelve days' record would be included. I have taken, however, four of these data sheets with their respective curves plotted for water consumption, and again it is to be noted how very closely the data sheets and curves check one another. Careful measurements of coal weights were made, in order to secure the resulting rate of evaporation which is given, and is noted to approximate seven pounds of water per pound of coal.

Test No. 4-A
Harlem River Yard, April 13, 1910.
Water used, 37,200 lb.
Anthracite coal used, 5,700 lb.
Apparent evaporation, 6.53 lb.

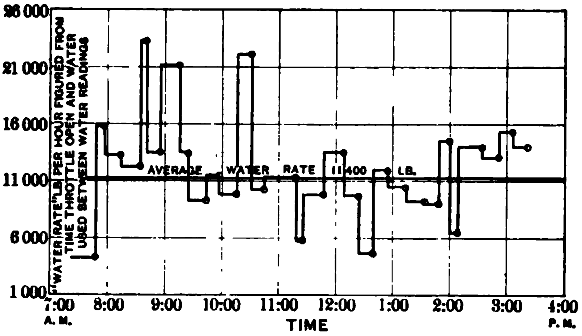

FIG. 21.—Water and coal consumption on switch engine

As an interesting record of the practical method of coaling a switching locomotive for an eight-hour shift, herewith are quoted the words of the engineer in his report with reference to these tests:

"About a half hour before going to work each morning the tank was loaded with 8000 lb. of hard coal. The engine was then taken to the pit and fire cleaned, and a new fire of coal built in her. To build this first fire required about 2,500 lb. of coal, and the engine worked on it for about three hours. At the end of three hours the grates were shaken and the fire dressed and built up with about 1500 lb. more coal. This second fire lasted about two hours, and at the end of that time the grates were again shaken, fire dressed and the third and last fire built. This required about 1500 lb. and lasted until the finish of the eight hours' work.

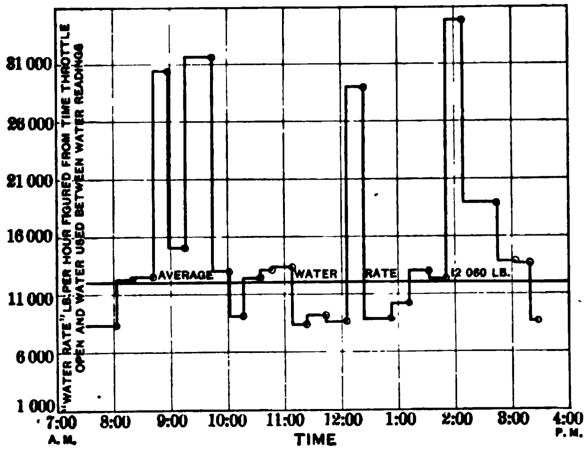
Test No. 8-A
Harlem River Yard, April 21, 1910.
Water used, 38,700 lb.
Anthracite coal used, 5,450 lb.
Apparent evaporation, 7.10 lb.

FIG. 22 —Water and coal consumption on switch engine

"After the day's work was completed the engine was taken to the house with coal remaining on her, and enough coal left in the tank to keep the fire until the next morning when the engine went to the pit to have fire cleaned and built up for the day's work".

It would be to go ahead of our story to speak of an electric switcher here, but does not the above described operation suggest it?

Again, space does not offer the opportunity to discuss the hourly movement of the engine in the yard. One brief paragraph from the testing engineer's report will suffice:

"When not pulling and loading floats the engine was employed making up trains to load floats, and doing other miscellaneous work".

Not uninteresting, too, is the closing paragraph of his report, which quoted is as follows:

"On following the work of engines, one is forced to the conclusion that the ratio of weight to tractive effort is too low. This may be due to poor trackage, road-bed, etc., but even with sanded rails and all other conditions available the engines are inclined to slip, thus losing time in accelerating. This is a bad fault in a switching locomotive, and especially bad in such yards as Harlem River and Oak Point, for since the speed is limited and the coupling, uncoupling, connecting air, etc., can be only done so rapidly, the only method of increasing the amount of work done is to increase the accelerating power of the engine used". There is, of course, this much to be taken into consideration—that the more constant torque of an electric locomotive accelerating a drawbar pull would have less tendency to slip than a steam locomotive accelerating that same pull.

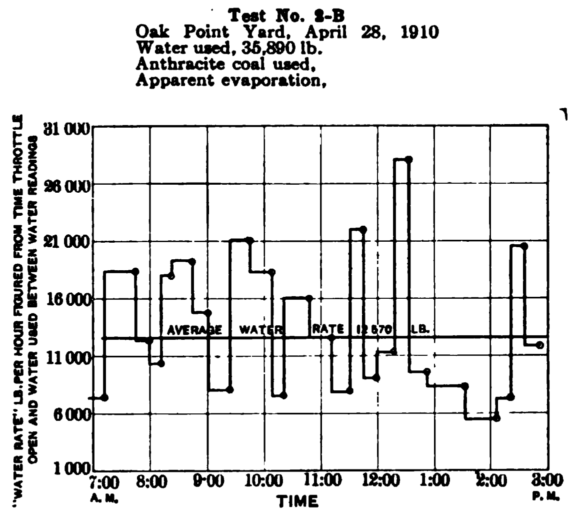

FIG. 23.—Water and coal consumption on switch engine

Tables 2, 3, 4 and 5 and curves Figs. 20, 21, 22 and 23, for April 8, 13, 21 and 28, which, by the way, were taken at random show operating data as follows:

TABLE 2.

LOG OF TEST NO 1-A

HARLEM RIVER YARD ENGINE NO. 2392 APRIL 8, 1910

Time	Avg. boiler press	Throttle open		Engine in motion		Engine Standing		Total cars handled		Water lb.	Water rate lb. per hour
		M.	S.	M.	S.	M.	S.	L.	E.		
8:00 8:13	200.0	3	0	8	0	5	0	3	0	561.8	11,240
8:13 8:28	200.0	6	35	12	40	2	20	30	4	936.3	8,530
8:28 8:42	191.7	5	20	9	25	4	35	6	6	811.5	9,130
8:42 8:53	201.0	5	45	8	25	2	35	31	10	1935.0	20,190
8:53 9:10	197.5	5	50	9	25	7	35	2	3	811.5	8,350
9:10 9:23	196.7	6	35	10	10	2	50	16	0	1748.0	15,930
9:23 9:41	200.0	4	30	5	0	13	0	Note		749.0	9,990
9:41 10:13	198.0	9	35	15	30	16	30	23	0	1810.0	11,330
10:13 10:31	196.3	8	30	10	10	7	50	61	0	2184.0	15,420
10:31 10:51	190.0	12	40	18	10	1	50	28	35	2497.0	11,830
10:51 10:55	195.0	1	15	2	25	1	35	3	0	374.6	17,980
10:55 11:14	202.0	8	30	14	35	4	25	17	12	1748.0	12,340
11:14 11:27	202.5	3	15	4	30	8	30	6	6	624.0	11,520
11:27 11:40	201.0	8	00	9	0	4	0	19	13	2247.0	16,850
11:40 12:02	200.0	6	55	11	35	10	25	52	0	1997.0	17,320
12:02 12:15	201.7	3	10	5	45	7	15	17	0	1061.0	20,110
12:15 12:38	197.5	7	55	12	0	11	0	66	0	1311.0	9,940
12:38 12:58	199.0	8	0	12	50	7	10	15	57	1873.0	14,050
12:58 1:36	200.8	6	35	13	45	24	15	53	0	2747.0	25,030
1:36 1:53	200.0	3	20	7	10	9	50	23	0	1248.0	22,470
1:53 2:01	200.0	6	0	6	50	1	10	40	0	936.0	9,360
2:01 2:15	196.7	5	10	8	25	5	35	14	1	1186.0	13,770
2:15 2:34	200.0	4	50	7	50	11	10	20	0	1436.0	17,820
2:34 2:42	197.5	2	10	3	40	4	20	15	0	749.0	20,740
2:42 2:56	201.3	3	30	8	45	5	15	29	0	1623.0	27,820
2:56 3:20	200.0	5	35	10	55	13	5	26	0	1436.0	15,430
3:20 3:35	191.7	7	10	11	20	3	40	24	0	1935.0	16,200

Note—Pull car on track.

Total length of time of shift........................7 hr. 35 min.

Total time throttle open............................2 hr. 40 min. or 35% of total

Total time engine in motion..........................4 hr. 18 min. or 57% of total

Total time engine standing..........................3 hr. 17 min. or 43% of total

Total water used.....................................38,600 lb.

Total anthracite coal fired.......................... 5,540 lb.

App. evaporation..................................... 6.98 lb. of water

Average rate of water used per hour, figured from water used and time throttle open between water readings, 14,500 lb. of water.

TABLE 3.

LOG OF TEST NO. 4-A

HARLEM RIVER YARD. ENGINE 2392. APRIL 13, 1910.

Time		Avg. boiler press	Throttle open		Engine in motion		Engine Standing		Total cars handled		Water lb.	Water rate lb. per hour
			M.	S.	M.	S.	M.	S.	L.	E.		
7:20	7:48	202.5	9	25	17	0	11	0	22	14	687	4,380
7:48	7:57	195.0	4	0	8	45		15	8	10	1061	15,910
7:57	8:14	199.3	8	55	12	45	4	15	26	27	1997	13,440
8:14	8:35	198.3	6	25	12	45	8	15	32	3	1311	12,260
8:35	8:40	200.0	2	15	2	40	2	20	9	7	874	23,300
8:40	8:56	200.0	5	25	10	55	5	5	21	13	1124	13,560
8:56	9:16	202.5	3	0	4	55	15	5	18	2	1061	21,220
9:16	9:24	195.0	5	30	6	10	1	50	38	2	1248	13,610
9:24	9:43	191.3	10	50	14	45	4	15	25	36	1685	9,330
9:43	9:57	198.8	5	50	11	40	2	20	17	23	1124	11,560
9:57	10:16	201.0	9	45	15	15	3	45	31	20	1623	9,990
10:16	10:32	200.0	5	45	12	0	4	0	7	9	2122	22,140
10:32	10:45	202.5	4	0	8	10	4	50	9	5	687	10,310
10:45	11:19	201.7	14	20	25	50	8	10	26	17	2746	11,490
11:19	11:26	195.0	4	30	16	10	1	0	4	1	437	5,830
11:26	11:48	195.0	9	45	19	15	2	45	26	19	1623	9,990
11:48	12:09	200.0	6	20	8	10	12	50	13	11	1436	13,600
12:09	12:25	199.0	7	10	11	20	4	40	20	29	1186	9,930
12:25	12:40	200.0	7	40	11	15	3	45	12	5	624	4,880
12:40	12:56	195.0	6	50	9	15	6	45	49	5	1373	12,060
12:56	1:15	192.5	8	50	14	20	4	40	18	12	1560	10,600
1:15	1:34	196.3	8	5	15	15	3	45	26	22	1248	9,260
1:34	1:49	192.5	6	10	10	35	4	25	14	15	936	9,110
1:49	2:00	200.0	4	20	5	25	5	35	9	7	1061	14,690
2:00	2:08	200.0	5	10	6	15	1	45	9	7	562	6,530
2:08	2:34	193.8	5	35	10	5	15	55	22	4	1311	14,100
2:34	2:53	191.3	8	50	14	15	4	45	39	4	1935	13,020
2:53	3:06	202.5	2	55	6	5	6	55	3	5	749	15,410
3:06	3:20	197.5	7	45	10	10	3	50	24	35	1810	14,010

Total length of time of shift........................8 hr. 0 min.
Total time throttle open..........................3 hr. 15 min. or 40.6% of total
Total time engine in motion.......................5 hr. 21 min. or 66.9% of total
Total time engine standing........................2 hr. 39 min. or 33.1% of total
Total water used..................................37,265 lb.
Total anthracite coal fired........................ 5,500 lb.
Approximate evaporation...........................6.53 lb. of water.
Average rate of water used per hour, figured from water used and time throttle open between water readings—11,400 lb. of water.

TABLE 4.

LOG OF TEST NO. 8-A

HARLEM RIVER YARD. ENGINE 2392. APRIL 21, 1910.

Time		Avg. boiler press	Throttle open		Engine in motion		Engine Standing		Total cars handled		Water lb.	Water rate lb. per hour
			M.	S.	M.	S.	M.	S.	L.	E.		
7:30	8:03	195.0	10	50	19	45	13	15	11	20	1498	83,000
8:03	8:22	195.0	8	15	14	5	4	55	46	5	1685	12,250
8:22	8:42	200.0	7	10	14	15	5	45	12	9	1498	12,540
8:42	8:58	202.5	2	35	4	40	11	20	4	2	1311	30,490
8:58	9:16	189.0	11	20	14	35	3	25	20	38	1873	9,920
9:16	9:45	190.0	3	25	6	50	22	10	2	2	1748	30,660
9:45	10:01	196.7	5	10	15	30	0	30	9	9	1124	13,050
10:01	10:17	197.0	8	15	13	25	2	35	57	5	1248	9,080
10:17	10:36	197.5	9	0	14	20	4	40	16	18	1873	12,490
10:36	10:48	193.3	5	25	10	30	1	30	18	24	1186	13,140
10:48	11:09	190.0	8	5	12	45	8	15	57	5	1810	13,440
11:09	11:24	195.0	4	5	8	15	6	45	6	2	624	9,180
11:24	11:45	192.0	9	0	15	10	5	50	58	5	2247	14,980
11:45	12:06	194.0	13	35	16	35	4	25	24	37	1935	8,550
12:06	12:24	197.5	4	45	9	30	8	30	5	2	2310	29,180
12:24	12:54	193.3	12	40	24	10	5	50	11	4	1873	8,870
12:54	1:13	192.5	4	45	10	50	8	10	9	14	811	10,250
1:13	1:34	190.0	7	10	13	55	7	5	7	11	1561	13,070
1:34	1:51	192.5	7	15	14	25	2	35	6	18	1498	12,400
1:51	2:09	197.5	2	15	3	50	14	10	7	2	1311	34,960
2:09	2:46	197.0	12	10	22	10	14	50	29	5	3870	19,080
2:46	3:05	195.0	6	25	12	40	6	20	19	4	1498	13,990
3:05	3:20	192.5	7	15	13	20	1	40	25	49	1685	13,945
3:20	3:30	187.5	4	20	6	30	3	30	4	2	624	8,640

Total length of time of shift........................8 hr. 0 min.
Total time throttle open............................2 hr. 55 min. or 36.5% of total
Total time engine in motion.........................5 hr. 12 min. or 65.0% of total
Total time engine standing..........................2 hr. 48 min. or 35.0% of total
Total water used....................................38,700 lb.
Total anthracite coal fired......................... 5,450 lb.
Approximate evaporation............................ 7.10 lb.

Average rate of water used per hour, figured from water used and time throttle open between water readings—12,060 lb. of water.

TABLE 5.

LOG OF TEST NO. 2-B

OAK POINT YARD. ENGINE 2392. APRIL 28, 1910

Time	Avg. boiler press	Throttle open		Engine in motion		Engine Standing		Total cars handled		Water lb.	Water rate lb. per hour
		M.	S.	M.	S.	M.	S.	L.	E.		
6:54 7:11	198.0	7	10	11	55	5	5	24	35	874	7,320
7:11 7:44	191.7	4	40	9	5	23	55	3	6	1436	18,460
7:44 7:59	187.0	7	30	11	25	3	35	53	18	1561	12,490
7:59 8:10	176.7	5	0	9	40	1	20	10	17	874	10,490
8:10 8:22	180.0	5	10	7	0	5	0	10	13	1561	18,120
8:22 8:44	191.7	7	45	15	5	6	55	44	6	2497	19,330
8:44 9:01	185.0	7	5	12	40	4	20	29	35	1748	14,810
9:01 9:24	188.8	10	35	18	25	4	35	16	25	1436	8,140
9:24 9:45	191.7	2	40	5	20	15	40	22	3	936	21,060
9:45 10:08	190.0	7	10	10	30	12	30	22	3	2185	18,290
10:08 10:20	190.0	5	25	9	30	2	30	15	35	687	7,610
10:20 10:48	193.3	7	40	14	30	13	40	0	3	2060	16,120
10:48 11:10	177.5	10	45	16	40	5	20	30	16	2247	12,540
11:10 11:30	182.5	11	20	19	20	0	40	18	28	1498	7,930
11:30 11:45	195.0	3	45	9	5	5	55	8	3	1373	21,970
11:45 11:59	180.0	10	10	13	45	0	15	48	31	1561	9,210
11:59 12:18	181.3	6	15	12	5	6	55	2	10	1186	11,390
12:18 12:33	186.7	6	15	12	25	2	35	11	13	2934	28,170
12:33 12:52	173.3	11	15	15	50	3	10	10	20	1810	9,650
12:52 1:32	190.0	7	30	15	0	25	0	0	6	1061	8,490
1:32 2:05	190.0	8	10	12	35	20	25	3	8	749	5,500
2:05 2:20	187.5	7	10	10	40	4	20	3	6	874	7,320
2:20 2:35	198.3	4	0	7	20	7	40	4	8	1373	20,600
2:35 2:52	200.0	7	0	12	30	4	30	10	15	1373	11,770

Total length of shift..............7 hr. 58 min.
Total time throttle open..........2 hr. 51 min. or 35.8% of total time.
Total time engine in motion.......4 hr. 52 min. or 61.1% of total time.
Total time engine standing........3 hr. 6 min. or 38.9% of total time.
Total water used................35,890 lb.
Average rate of water used per hour, figured from water used and time throttle open between water readings—12,570 lb. of water.

It is interesting to note the following averages:

1. Total time of throttle open.................36.7 per cent
2. Total time engine in motion................62.65 per cent
3. Total time engine standing..................37.5 per cent
4. Rate of water used per hour................12633 lb.
5. Total water used—7.5 hours..................37603 lb.

By these figures and the curves plotted we are able to get a close approximation of the average energy required to be delivered to the drivers of a switching engine, and what its maximum requirements are. Particularly interesting is the water rate of 12,633 lb. Assuming 40 lb. of water evaporated per horse-power-hour, which is probably much lower than the actual, it is seen that the average horse power ***during the time the throttle is open*** is approximately 313 h.p.; but it is noted that the engine is developing power for only 36.7 per cent of the time, and thus the average energy developed during the hour is approximately 115 h.p. The reduction of the energy developed by a switching engine to an average of 115 h.p. has been something of a revelation to the writer, and the two most important things it suggests are:

1. That in switching, yard speeds can be greatly increased by the use of an electric switcher of very much less engine capacity than that used in the steam switcher.
2. On account of the low average rate of energy required for their operation, a central power station will deliver at far higher efficiency the power necessary to the electric switching engine, than that obtained from the power plant individual to the steam switching engine itself.

Immediate application of this statement is seen in the ratio of the pounds of coal burned to the number of horse power hours developed, which is seen to be 6.4. Increasing this by the coal burned during the idle hours of the engine, this ratio approximates 8. It has been demonstrated, that the ratio between the coal burned for operating passenger trains by electric, rather than steam locomotives, is 1 to 2. In the case of switching engines this rate is much greater; a figure of 1 to 3 being conservative.

STATISTICAL RECORD OF SINGLE-PHASE TRUNK LINE OPERATION

In the paper entitled "The Log of the New Haven Electrification", presented before the A.I.E.E., by the writer in December, 1908, there was given a table of train minute delays with their causes and a set of graphical charts supplementing them, which gave a very fair idea of the general character of the service resulting in the early days of operation shortly after the construction had been sufficiently advanced to permit a trial of full operation between Stamford and New York City.

In Figs. 24, 25, 26, 27, 28 and 29, herewith, are given similar data for operation covering a consecutive period of six months—one year later; the service having by that time settled down to something of a more commercial character.

For the sake of comparison, it is interesting to place these tables and charts of six months' operation in proximity to each other. The tables of train minute delays for 1908 and for 1909 are therefore presented in the same illustrations, each with the same scale.

Individual and collective train-minute delays between New York and Stamford

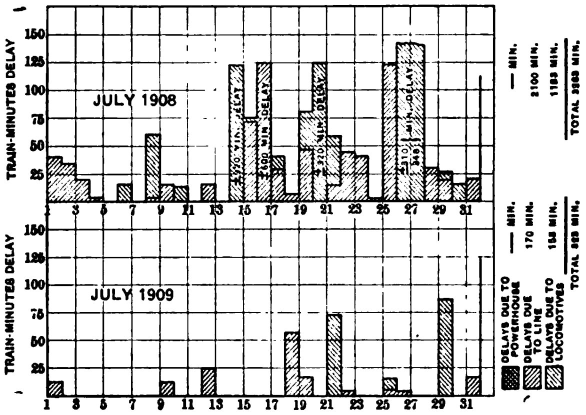

FIG. 24.—Train minute delays, July 1908–1909

Individual and collective train-minute delays between New York and Stamford

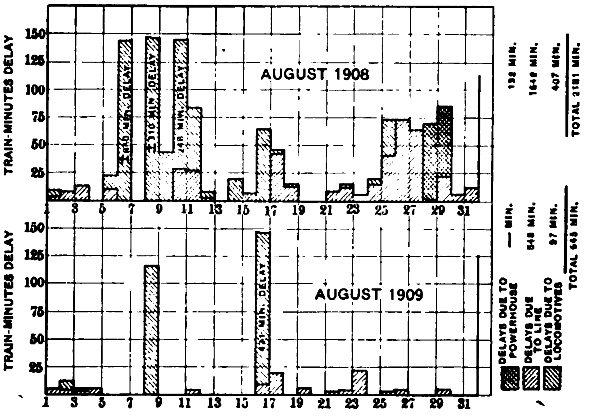

FIG. 25.—Train minute delays, August 1908–1909

Reproduced charts are inclusive of train minute delays over 300 minutes; which, for the reasons explained, were omitted by the author in his original paper.

The most interesting thing to note in these tables of more recent operation is the disappearance of delays, with the exception of one amounting to over 300 train minutes. The total train minute delays for the six months' consecutive operation in

Individual and collective train-minute delays between New York and Stamford

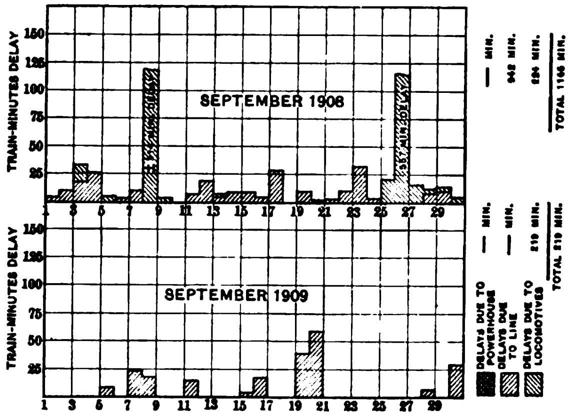

FIG. 26.—Train minute delays, September 1908–1909

Individual and collective train-minute delays between New York and Stamford

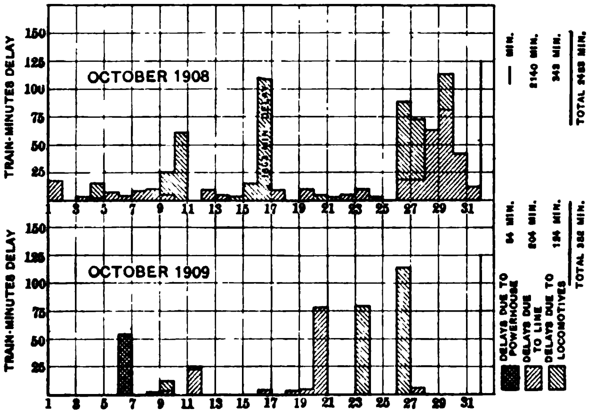

FIG. 27.—Train minute delays, October 1908–1909

1908 were 10,373 train minutes; and summing up the train minute delays for the six months' consecutive operation in 1909 we find the train minute delays to be 2,076. Thus, the train minute delays for the six months of 1909 were one-fifth of the train minute delays for 1908.

In the summation sheet shown in Fig. 30 it is interesting to note as a more intimate acquaintance with the system's characteristics and a better knowledge of the details that needed correction or change were impressed upon us in the regular log

Individual and collective train-minute delays between New York and Stamford

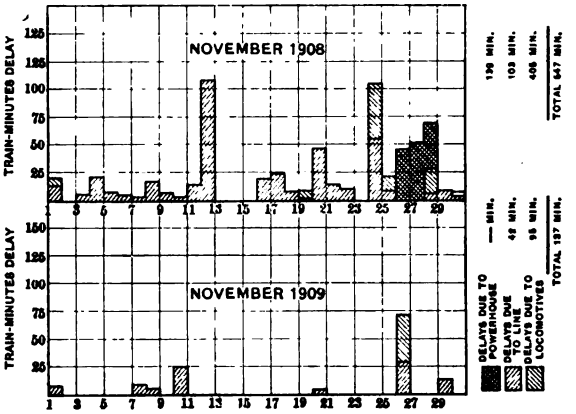

FIG. 28.—Train minute delays, November 1908–1909

Individual and collective train-minute delays between New York and Stamford

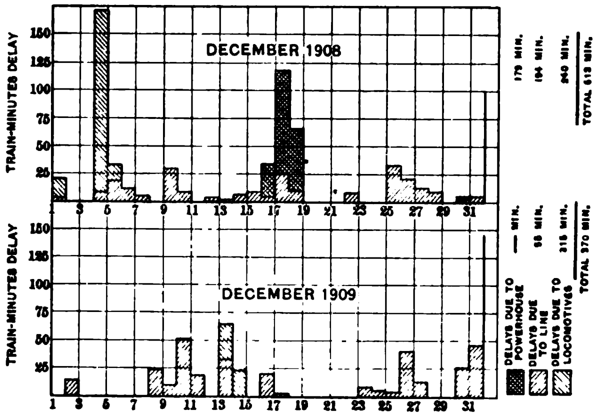

FIG. 29.—Train minute delays, December 1908–1909

of operation, the train minute delays steadily decreased, with the exception of one month (in October 1908) in which, as brought out in the author's previous paper, there was a serious power house delay, due to the explosion of an oil switch. The delays as shown in the same figure for the six months of the year following show the system's stability of operation, and this was anticipated by those who had not composed its obituary in the early days of its first trial.

The author has been criticized by his engineering friends for having written the earlier paper at a time when so poor a record of operation would have to be shown; but it was his thought at the time that no harm could possibly be done by a revelation of the facts, and it was his estimate at that time that the criticism would be dissolved in the consideration of the actual facts that were contributary to the cause of the service rendered, and that later possibly such an opportunity as is now presented would arrive, when the justification of this stand could be sustained. Therefore, this record of operation one year after that presented in the original paper, is not offered in any sense as a proof of the reliability of service that can be produced by the single-phase system of train operation. This fact has been too plainly evident by the consensus of opinion expressed in the public and

Train minutes delay between New York and Stamford

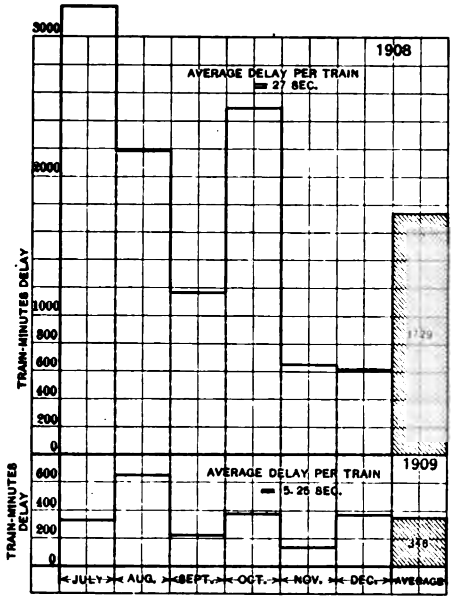

FIG. 30.—Tabular summation of train delays

technical press, indicating the satisfaction of the travelling public who have to use the New Haven electrification in their business. It is to be confessed by the author, however, that there is some personal satisfaction involved in making this invidious comparison between trial and practical operation, in recalling what some of my friendly sceptics had to say about our system, but in the same breath let me say that this is offered in no feelings of rancor or unfriendliness; on the contrary, this record of operation is presented with the hope that it may turn the thoughts of those former friends into the path, which before seemed such a difficult one in which to tread, the simplicity of which, after the first blare of false alarms is over, must now come into bold relief.

A comparison of the 1909 to the 1908 train minute delays is immediately indicative of the fact that even in this short time the disturbing factors of the system had disclosed themselves and had been eliminated. Eighteen months after commercial service was inaugurated our electrical failure report shows a record of over 15,700 miles per engine failure. Between the 2d and 23d of November, 1909, 66,000 electric locomotive miles were run off; and this mileage, which is approximately *eleven round-trips from New York to San Francisco,* was accomplished with a total of three minutes' delay. This kind of record is the ground upon which the Board of Directors of the New Haven road stood in ratifying the system and voting an extension to apply to all service—freight and passenger, inclusive of yards, terminals and main line west of Stamford.

These same eighteen months have yielded an abundance of new information concerning the characteristics of the system, inclusive of power house, line and locomotives. Though all of these departments contributed their share of train delays in our initial operation, the unlooked for troubles, which while not in any way fundamentally attacking the principles of the system, reflected upon it, for traffic delays are always a great factor in the public estimate, and have sometimes been misapplied as arguments against the system by those who should have discriminated between the incidental and the fundamental.

Comparison between Electric and Steam Operation. In Fig. 31 is an interesting relation between failures for trunk line service of electric *vs.* steam operation. As is to be noted in the lower diagram of the figure, the power house failures in its effect on engine mileage is practically nil. On account of the severe handicap that has been placed on the line by steam locomotive stack discharges directly beneath it, a number of failures per 100,000 engine miles are recorded. An elimination of the steam service under the electrified wires will greatly reduce, if not entirely eliminate, failures due to this part of the electrical system. In the upper diagram of the figure is shown the relation of electric engine mileage per failure *vs.* steam mileage. It is to be noted in this that the electric locomotive failures are nine per 100,000 electric engine miles, while the steam, which is an average figure for all of the divisions of the New Haven, is 21. Thus,

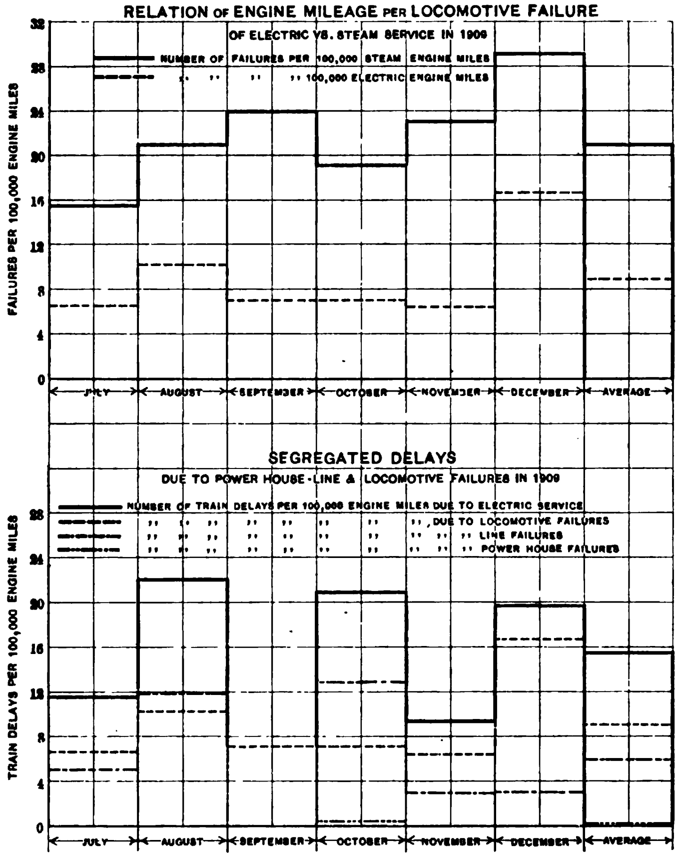

FIG. 31.—Relation engine mileage to failure

the electric locomotive service is 133 per cent better than the steam.

POWER HOUSE

The power house of a single-phase system does not differ essentially from the power house which generates high-voltage three-phase current for distribution to substations where it is converted for direct-current car propulsion, except that greater care should be taken to include higher factors of insulation, due to one phase being grounded. In case of the before-mentioned system, as none of the phases are grounded (even at times a ground on the neutral of star-wound generators being omitted) the failure of an insulator does not produce as severe a short circuit (if any) as that produced in the case of the single-phase grounded system. A simple expedient, however, has been devised to alleviate this effect by the introduction of impedance in the leads of the single-phase generators, which confines the short-circuiting stresses within the windings of the generating equipment to figures well within proper safety factors. Indeed, many of the large capacity power and lighting companies are taking up the matter of the installation of impedance coils for their ungrounded systems—a step which seems to me wise.

Our experience with three-phase generators indicates that their choice, as against single-phase, is the proper one. The three-phase star winding offers at all times a spare leg in any of the generators, in the event of any trouble with the two other legs; and at the same time permits simultaneous supply of current from the same generating system for the operation of either three-phase or single-phase apparatus. In the case of the Cos Cob station, this is instanced in the fact that we are supplying three-phase current for our Greenwich lighting plant and are now arranging for the supply of power for the operation of substations at White Plains, Mamaroneck, Portchester, Stamford, South Norwalk and Bridgeport; in which substations there will be operated motor-generator or synchronous converter outfits for the supply of direct current for railway purposes at the above mentioned places.

By the installation of copper-clad rotating fields in our generators, the unbalanced voltage between phases is reduced to a minimum, and such as remains is easily compensated for by arrangement of transformer taps in the substations reducing the three-phase current from high to low voltage for motor or synchronous converter application.

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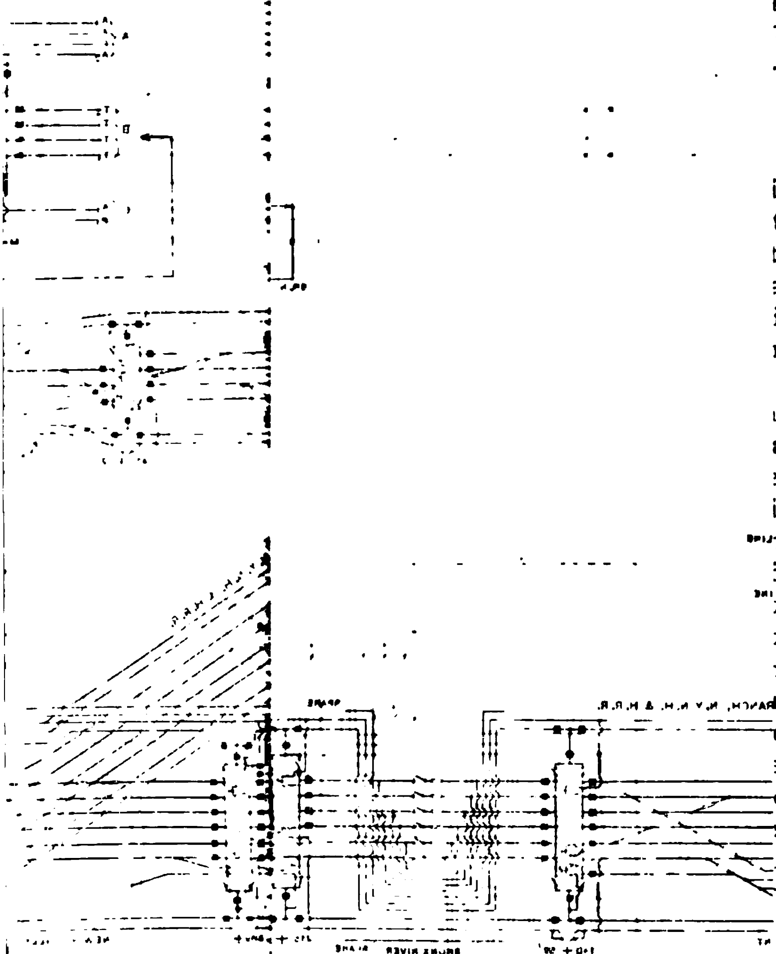

83.—General wiring

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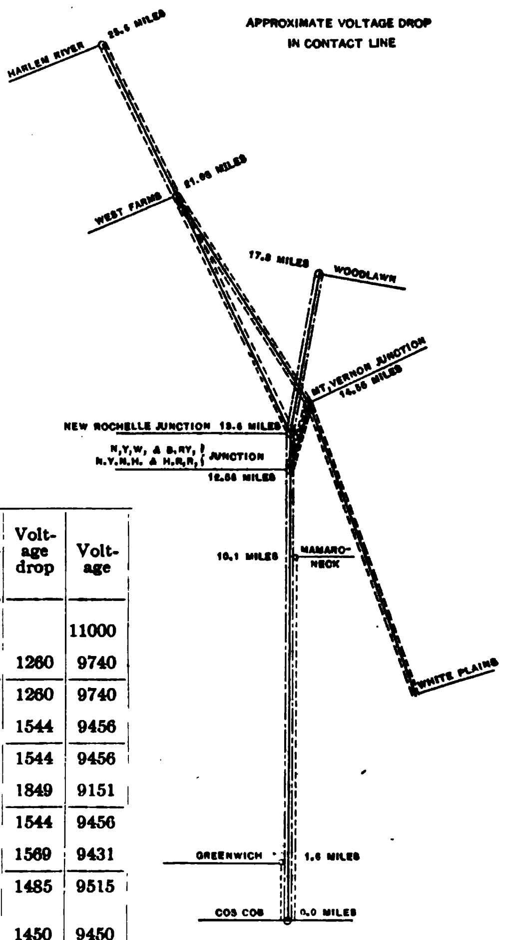
DISTRIBUTION SYSTEM

As indicated in the general wiring diagram of the system, Fig. 32, this is a unit system comprehending the main line of the New York New Haven & Hartford road between Stamford and Woodlawn, the six-track Harlem River freight and passenger connection from New Rochelle to the Harlem River Terminal., New York City and the New York, Westchester and Boston line running from the West Farms connection to the Harlem River Branch up to White Plains, N. Y. It is seen that throughout this extensive area, embracing in all over 300 miles of single track, there is not a single substation and no electrical pressure higher than 11,000 volts is used. It is further to be noted that all of the copper installed over the tracks just above the steel contact wire is in the same phase unaugmented by any feeders other than the by-pass wires installed on the lower cross-arms of the catenary posts to permit sectionalization of anchor bridges.

Of interest, also, is the very successful control system common to all of the sectionalizing breakers throughout this triple arrangement of distribution, the function of which is to insure a reliable selective action of circuit breakers to confine any line trouble to its specific locality, and thus making immune all other parts of the line. Briefly described, the control consists of a single wire, upon which is impressed the normal voltage of the system when a short circuit occurs anywhere, but not until the automatic resistance at the power station has been cut in series with the line; at which moment the control wire through transformers passes current through the tripping coils of the sectionalizing breakers, and the two breakers that are directly feeding the short circuit are immediately opened. The resistance, thus inserted, however, has reduced the short-circuiting current to a minimum and relieved greatly the duty of the opening breakers. The resistance scheme above mentioned, has proved itself to be a most valuable acquisition to the system, serving at once to lessen the duty on both generating and distributing apparatus.

The Reach of System. In Fig. 33 is shown the route arrangement of the three combined main lines—the New York New Haven and Hartford, the New York Westchester & Boston and the Harlem River Branch.

In the aforementioned, the first comprises a route of four tracks, the second a combination of four and two tracks, and the



	Cross section		Voltage drop	Voltage
	Catenary	Feeder		
Cos Cob	4/0000	4/0000		11000
Mamaroneck			1260	9740
Marmaroneck	4/0000	4/0000	1260	9740
New Rochelle			1544	9456
New Rochelle	6/0000	2/0000	1544	9456
Harlem River	4/0000		1849	9151
New Rochelle	4/0000	2/00	1544	9456
Woodlawn			1569	9431
N. Y. W. & B. Ry. Junct. N .Y. N. H. & H. R.R.	2/0000	4/0000	1485	9515
Mount Vernon			1450	9450
Mount Vernon	4/0000	2/0000	1450	9450
West Farms			1725	9275
Mount Vernon	2/0000	2/0000	1450	9450
White Plains			1730	9270

FIG. 33.—Approximate voltage drop and route diagram.

third six tracks. Depending upon the number of tracks, there is provided always a varying conducting capacity of the over head wires and return rails. Throughout there is installed over each track one 4/0 copper conducting wire and one 4/0 steel contact wire; the latter suspended from the former by metallic clips. For future calculations it is essentially necessary to note the transmission characteristics of the overhead and track circuits, and to that end a very careful investigation was made to determine the constants of resistance of overhead wires and rail return, their individual and mutual reactance and the resultant impedance of these two right-angular drop-producing components.

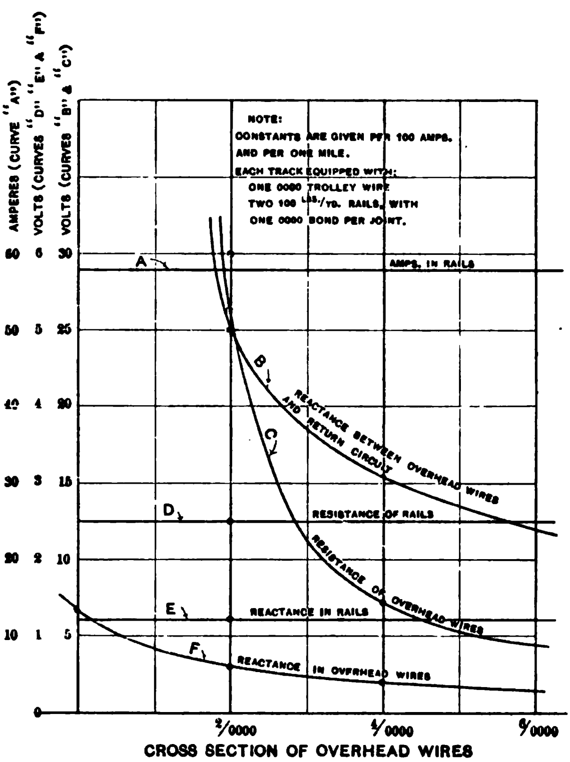


FIG. 34.—Constants for two-track equipment

The constants were worked out for two, four and six tracks and the curves of Figs. 34, 35 and 36 are the graphical result of the investigation.

It is interesting to note what the maximum drop on the system may be for conditions of peak load, and applying the constants as given by the curves it is seen that under maximum supply of power from Cos Cob station (during the 5:30 afternoon suburban load peak) the voltage at Harlem River Station, which is 25.6 miles from Cos Cob, is 9,151 volts—entirely sufficient to maintain all passenger and freight trains on schedule and to furnish at the same time the necessary power to switching engines doing duty on 100 miles of classification and switching yard tracks, which are a part of the Harlem River Branch electrification, and which are located most remotely from the power house.

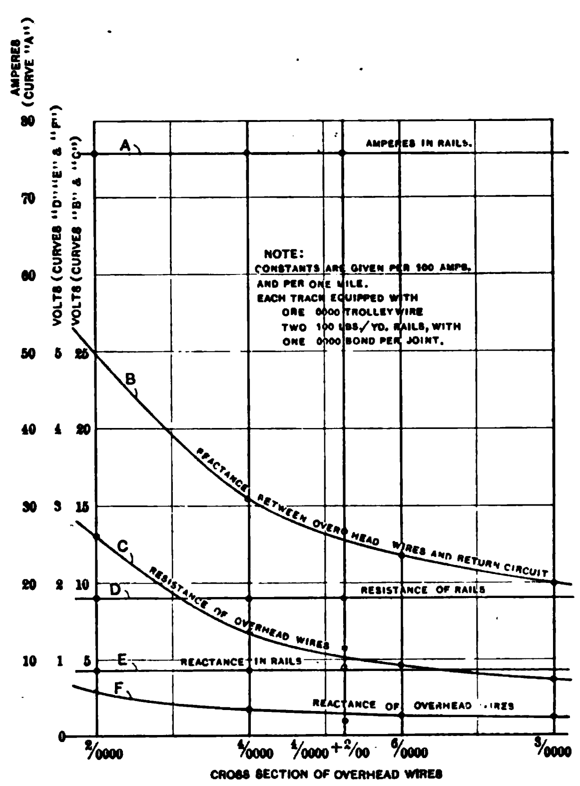
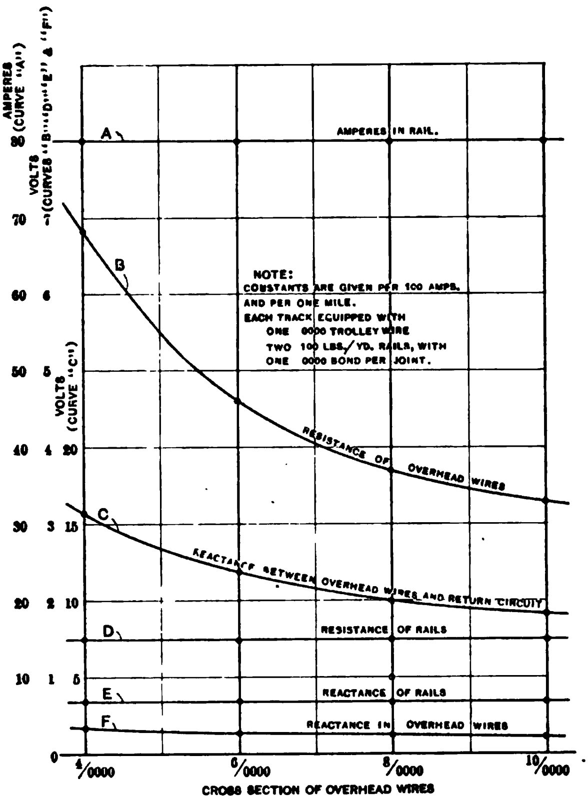


FIG. 35.—Constants for four-track equipment

Here, therefore, we see on a great scale history repeating itself, for it has ever been true where a large quantity of power and distance of transmission are combined, alternating current has been the chosen agent of transfer.

Voltage Regulation. The maximum conditions of peak load obtain on the so-called " Football Day " (when Yale University plays either Princeton or Harvard at New Haven). On November 19, 1910 the maximum peak at the power house for this day was 16,000 kw. Fig. 37 gives an all-day voltage chart showing synchronous clock-recording voltmeters registering the potential in three places—the power house, Mamaroneck tower and Mt. Vernon Tower; the latter being the junction of the New Haven with the New York Central Electrification (18 miles from the New Haven Power Station). In the morning hours the trains are dispatched to New Haven with a considerable more



NOTE:
CONSTANTS ARE GIVEN PER 100 AMPS. AND PER ONE MILE.
EACH TRACK EQUIPPED WITH
ONE 0000 TROLLEY WIRE
TWO 100 LBS./YD. RAILS, WITH
ONE 0000 BOND PER JOINT.

FIG. 36.—Constants for six-track equipment

headway than the same returning trains at night. This is indicated by the heavier drop in voltage due to the concentration of the evening load between the hours of 5:00 and 9:00. It is thus seen that the maximum line drop for this extraordinary day at the *end* of the line is 14 per cent; that the average drop at the *end* of the line is 4 per cent. Taking 75 per cent of this average drop at the *end* of the line for the general transmission of power to locomotives over the complete distributing system, it is seen that the average line loss for this maximum day was practically 3 per cent.

Storage batteries for trunk line electrifications are not economical. This is true whether the propulsion current be direct or alternating. It is true that the storage battery does smooth out the power station load and lowers the rate of cost of producing a kilowatt-hour, but the thing that concerns us quite as much as the rate of cost is the total amount of kilowatt-hours manufactured in payment for the luxury of the battery. A train service requires a certain number of kilowatt-hours. A plant producing these kilowatt-hours will be required to manufacture more energy with than without a battery on its distributing system.

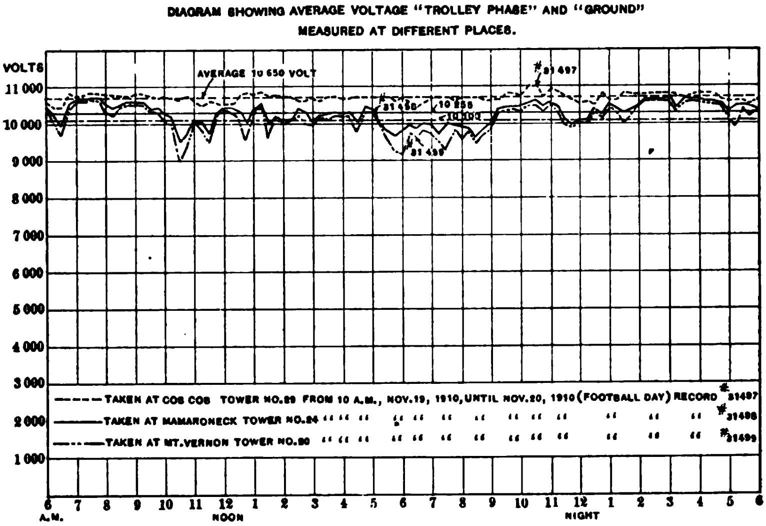


FIG. 37.—Drop on lines—Bristol chart

In general it may be stated that more kilowatt-hours means more coal, if the efficiency of generation is the same. As a matter of fact, the efficiency of electric energy production is higher with than without the battery, on account of the greater constancy of load for the former conditions, but the difference is so small that it is, at least for trunk line conditions, offset by the increase of output required and the cost of maintenance of the battery. On account of the established reliability of generating equipment the argument for the use of a storage battery for the supply of power in the event of power station breakdown is now no longer one of serious consideration, and so I think it is of interest to note the passing of the storage battery theory; at least in as far as its application to trunk line conditions is concerned.

In this connection should be noted the great importance of the added freight and switching loads in improving the station load factor, due both to the physical exclusion of freight trains from main tracks during the hours of passenger peaks and to the latitude of operation afforded in fixing freight schedules; thus discharging the functions of a battery, while escaping the penalties of battery losses and maintenance charges. Bearing directly on this point I quote from Mr. McHenry's report to the Commission appointed by the Massachusetts State Legislature to consider the subject of electrification within the Metropolitan District of Boston as follows:

> Power stations if provided for passenger requirements only, will have a large unused capacity between the hours of peak load, which otherwise could be utilized to very good advantage for the transportation of freight, and more particularly as the occupation of tracks by passenger trains during the hours of peak load acts automatically to limit the simultaneous operation of freight trains at such times. Thus, little or no additional investment in power houses is required to freight operation, and similarly the overhead track equipment serves equally well for both passenger and freight traffic, which makes it practicable to extend electric operation to include all classes of service at the cost of only the additional engines and the equipment of yard trackage required for freight service.
>
> It therefore seems quite safe to conclude that no general substitution of electric for steam traction should be made unless the substitution is complete, including passenger and freight operation and yard switching in addition, and also that in making such substitution the operation should be extended to include the full length of run or engine district, in order to avoid the uneconomical subdivision of the present " train runs ", together with the added expense and delays incident to intermediate engine transfer stations.

Insulation. There are points in the overhead system where the factor of insulation should be higher than at others. Practice has shown the wisdom of sectionalizing the lines at cross-overs. At these points it is necessary to bring the electrical catenary cables to a dead end and anchor bridges are supplied for that purpose. Oil switches must be provided for cutting in or out, as necessity may require, voltage on the lines thus dead-ended. In the order of their higher degree of insulation, requirements, I would mention:

1. Sectionalizing switches
2. Sectionalizing bus-bars.
3. Dead-end catenary insulators.
4. Intermediate catenary insulators.

As can be seen in the wiring diagram of the system Fig. 32 the whole track system leads into the anchor bridge buses, and a ground on them means an immediate effect on any wire connected to them. This reasoning is applicable to the switch, should the ground be on the bus bar side, and as the switch is a piece of moving apparatus, it is the more difficult to insulate and to keep insulated, and is therefore cited as the one deserving of the highest consideration of insulation.

The dead-end insulator has been mentioned third; let it be thoroughly understood, however, that it is in a class essentially its own, and worthy of respectful attention. No insulator throughout the past four years has had our more constant study. The difference between insulators not under and under mechanical strain while performing at the same time their electrical duty is marked. When the New Haven electrification was completed in 1908 the best dead-end insulator then on the market, and there were many firms competing, was one rated at 7,000 lb. mechanically and 40,000 volts electrically, and cost $27.00. We found in a very short time that two of these had to be used in series, which with the yoke harness made the cost $61. It is interesting to note here that in order to secure an insulator strong enough mechanically to withstand a cross catenary span in the electrification of our Portchester yard we had to design a yoke to hold two of the above insulators in multiple. To-day we have placed orders for dead-end (or strain) insulators, everyone of which is tested before shipment for 110,000 volts under a mechanical strain of 35,000 lb., and they have an ultimate mechanical tensile strength of 50,000 lb. The greatest credit is due the manufacturing companies who have developed this part of the art to this magnificent result. Indeed, the whole success of the high-voltage contact system depended upon such an attainment; and I can say, that I no longer have any moments of anxiety on this score, and consider that any further advance will be principally along the line of economy in manufacture. The insulator above described retails at $7, instead of $61; is capable of withstanding seven times the ultimate mechanical strength and three times the electrical strain of the original. This, in the vernacular of our American language, I think, is " some progress ".

Steel Contact Wire. It is difficult to place sufficient emphasis on the importance and value of the steel contact wire which was suggested by Mr. McHenry and put in service on the New Haven Lines in 1908. Its adoption accords with the general practice represented in bridge construction. Previous to its adoption we had practically been running on the members, rather than the floor of our electrical suspension bridge. Every highway bridge, from the smallest to the largest, carries inexpensive and replaceable floor material. Likewise, now, in our catenary bridge, its floor is inexpensive and replaceable. Its members (electrical conductors) are not being weakened and its floor, though cheap in first cost, has a long life. Interesting figures to bring out the life of this floor are given in table 6 that follows, showing micrometer measurements of the steel wire taken at a point of maximum wear directly in front of one of our low highway bridges where the steel wire is on a gradient of 2 per cent; thus assuring a maximum upward vertical force of contact with the pantagraph shoe of the locomotive. It is interesting to note from these readings that the actual vertical wear of the wire since its first installation thirty months ago, is .028 in., which is practically 4.5 per cent per year of the half diameter of the wire (one half taken to permit wire to be held in clips) which, even on this vertical diameter basis, indicates a life of over twenty years; but as a matter of fact it will be much more than this, for the reason that as the vertical diameter lessens the breadth of contact increases throughout, thus diminishing the rate of vertical wear. Of further interest, too, is the fact that there is practically no corrosion on the wire; for, like the traffic rails in service (only much more so) the wire is constantly covered by a film of grease—due to a generous amount of this material being placed on the pantagraph shoe.

The steel wire is, in effect, a longitudinal spring of constant length, in which the tension only varies with the temperature. The coefficient of expansion of the contact wire and its sup-

TABLE 6.

VERTICAL MEASUREMENTS OF TROLLEY WIRE ON TRACK NO. 3

Diameter in inches

	9/3/08	12/10/08	2/17/09	12/15/09	2/26/11
Bridge 245	0.483	0.475	—	0.487	0.486
Center of span	0.484	0.480	0.487	0.483	0.467
Bridge 244	0.486	0.483	0.484	0.481	0.444
Bridge 238	0.487	0.483	0.483	0.478	0.475
Center of span	0.476	0.483	0.480	0.458	0.440
Bridge 237	0.483	0.474	0.475	0.462	0.443
Bridge 231	0.486	0.486	0.482	0.472	0.453
East approach Low bridge 40	0.483	0.478	0.477	0.459	0.429
Center approach Low bridge 40	0.479	0.473	0.471	0.443	0.422
West approach Low bridge 40	0.478	0.447	0.476	0.445	0.423
Bridge 230	0.484	0.470	0.474	0.470	0.457
Bridge 226	0.482	0.479	0.478	0.461	0.444
Center of span	0.483	0.472	0.476	0.457	0.425
Bridge 225	0.480	0.478	0.476	0.453	0.430
Bridge 222	0.478	0.481	0.472	0.470	0.445
Center of span	0.487	0.481	0.456	0.462	0.429
Bridge 221	0.490	0.489	0.496	0.461	0.450
Bridge 214	0.484	0.484	0.479	0.475	0.467
Center of span	0.484	0.460	0.477	0.441	0.432
Bridge 213	0.472	0.467	0.470	0.460	0.455
Bridge 160	0.476	0.470	0.471	0.466	0.462
East approach Low bridge 27	0.475	0.480	0.466	0.463	0.463
Center of low bridge	0.469	0.474	0.474	0.467	0.432
West approach low bridge	0.476	0.469	0.465	0.466	0.446
Bridge 159	0.478	0.475	0.478	0.472	0.464
Bridge 150	0.471	0.470	0.467	0.460	0.459
East approach Low bridge 25	0.471	0.478	0.480	0.474	0.469
Center of low bridge	0.480	0.477	0.470	0.472	0.465
West approach to Low bridge	0.476	0.477	0.476	0.477	0.468
Bridge 149	0.486	0.475	0.472	0.474	0.468
Bridge 147	0.501	0.508	0.504	0.500	0.493
East approach low bridge (24)	0.478	0.476	0.490	0.482	0.471
Center of low bridge	0.502	0.500	0.492	0.489	0.465
West approach low bridge	0.503	0.498	0.505	0.491	0.490
Bridge 146	0.486	0.491	0.488	0.479	0.478
Center of span	0.492	0.488	0.480	0.485	0.482
Bridge 145	0.496	0.498	0.485	0.483	0.478
Bridge 142	0.472	0.474	0.474	0.466	0.457
Bridge 137	0.471	0.474	0.469	0.465	0.462
Center of span	0.472	0.475	0.469	0.466	0.460
Bridge 136	0.478	0.480	0.478	0.474	0.472

porting catenary cable being the same, the difficult and objectionable adjustments which are incident to a combination of copper and steel are avoided.

It was thought, that the extreme variations in temperature might cause the contact wire to break, but this feature, happily, has not manifested itself. Our experience with this steel wire justifies its presence, and it will be used throughout our catenary construction over the New York, New Haven and Hartford, Harlem River Branch and the New York, Westchester & Boston electrification; thus serving something over 300 miles, measured in single track.

ELECTRIC LOCOMOTIVES

In the writer's previous paper there was given a list of mechanical and electrical changes that were being made in the New York, New Haven and Hartford passenger type of locomotive and in the two years past an excellent opportunity has afforded to observe the result. No better index of the result could be evidenced than by the train minute delay statistics for six months of consecutive operation previously cited. As is always the case, new designs and practices include theoretical features which in practice are generally transformed into nuisances. The New Haven locomotives were no exception to this rule. Handicapped by the imposed condition of interchangeable operation on alternating- and direct-current systems—even with this complication to start with—to-day a closer inspection of the actually necessary control shows great simplification. The simplicity of the straight alternating-current single-phase control above all others can hardly be argued.

The introduction of a completely cushioned locomotive (with the exception of the wheels and axles) on heavy trunk line rails was one of keen interest to the maintenance-of-way department, and a careful study of its effect is being made. They have already reported a decided betterment of rail life and alignment since its introduction. Indeed it is not difficult to appreciate this natural result, due to the absorption of wheel impacts by the locomotive springs rather than by the track. In the quill spring arrangement as installed on the first New Haven locomotive the actual impact forces were under-estimated and the quantities of helical springs broken gave ample evidence of the deleterious forces at work. A much stronger set of helical springs was the answer. The quill drive with its various arrangements of spring support, by helical, tangential or other method, must answer to the charge of placing a greater first cost on the locomotives. The real question involved, is whether the interest on this cost and maintenance charges will offset the cost of repairs to track and equipment. There is abundant evidence in our hands to prove that it will do so many times.

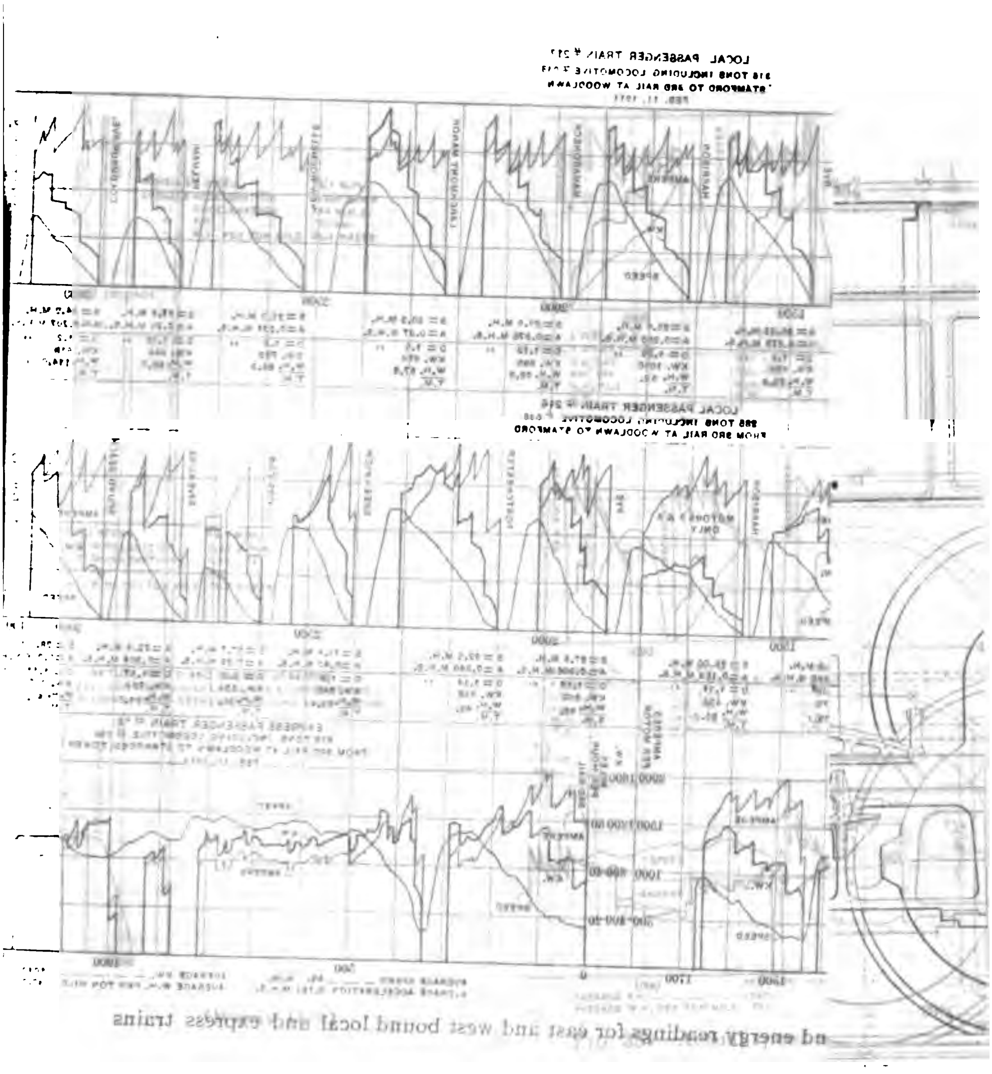
The initial installation of the New Haven road provided for locomotive propulsion of all trains. This provision has proved wise, in view of the schedule requirements permitting this type of equipment, and during the past two years close attention has been given to the development of three other classes of equipment, namely: the multiple-unit train, the road freight engine and the switching engine. In the paper previously referred to, the passenger locomotive was discussed.

In Figs. 38 and 39 are shown the run curves as obtained from electric passenger locomotive 038, a locomotive typical of the original 41 ordered for express and local service between Stamford and Woodlawn. Fig. 38 has for its abscissae reference the time. In order, however, to bring out the relation of grade to power, Fig. 39 uses for its abscissæ the station location, with grade co-ordinated with it. In this figure the effect of grade on the required input of locomotive is very remarkably brought out.

In express train No. 9 it is to be noted that locomotive 038 is handling a train weighing 475 tons; the maximum weight mentioned in specifications for purchase of these locomotives was 250 tons. The trailing weight of this train was 377 tons; thus the weight carried is 50 per cent in excess of specification.

In the case of the local passenger train No. 213, it is to be noted that its weight is 316 tons, giving a trailing load of 214. For local service a maximum trailing load of 200 tons was specified, but it is to be noted by the areas plotted for kilowatt input that the locomotive is very much underloaded. The choice of train weights in these two tests was at random, and the tests conducted were upon trains in commercial service.

In the case of the passenger runs, the stations between Stamford and Woodlawn being spaced very much closer than between Stamford and New Haven, did not permit as economical operation as in the case of the latter, due to the fact that acceleration is maintained nearly up to the point of braking in each case. A greater station spacing would have permitted more coasting, and thus a higher rate of economy in watt-hours per ton-mile. The use, however, of locomotives



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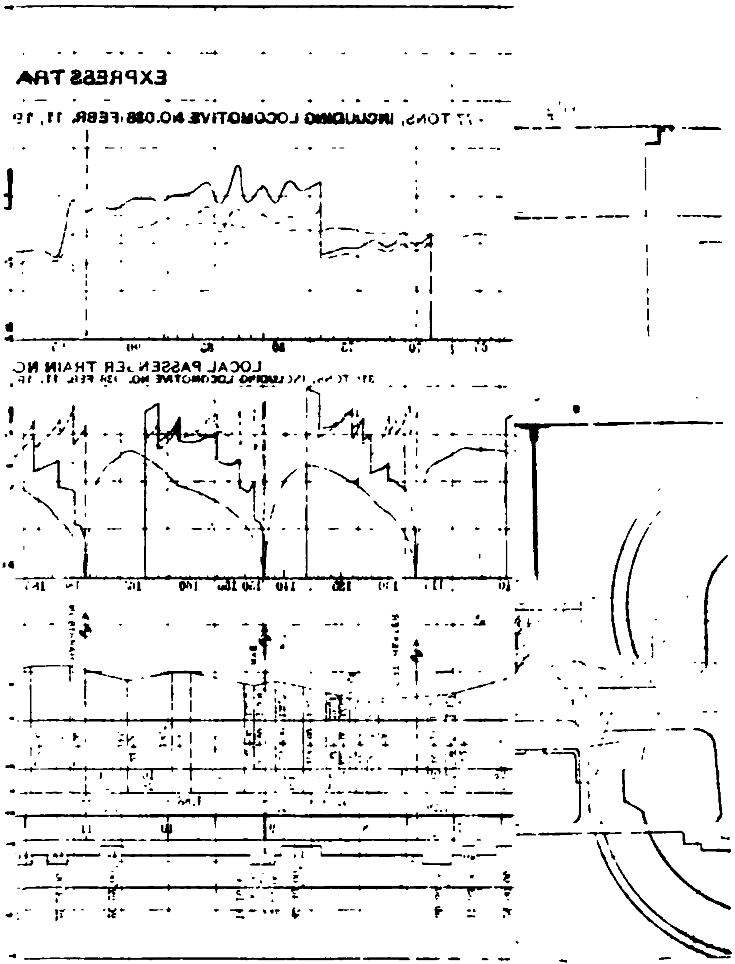

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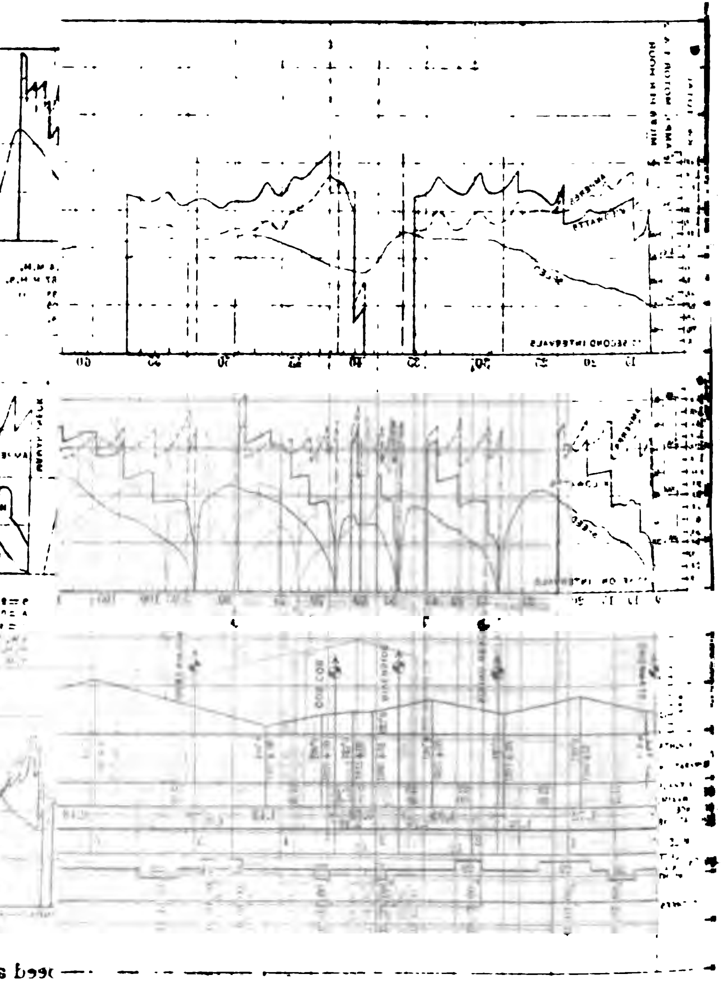

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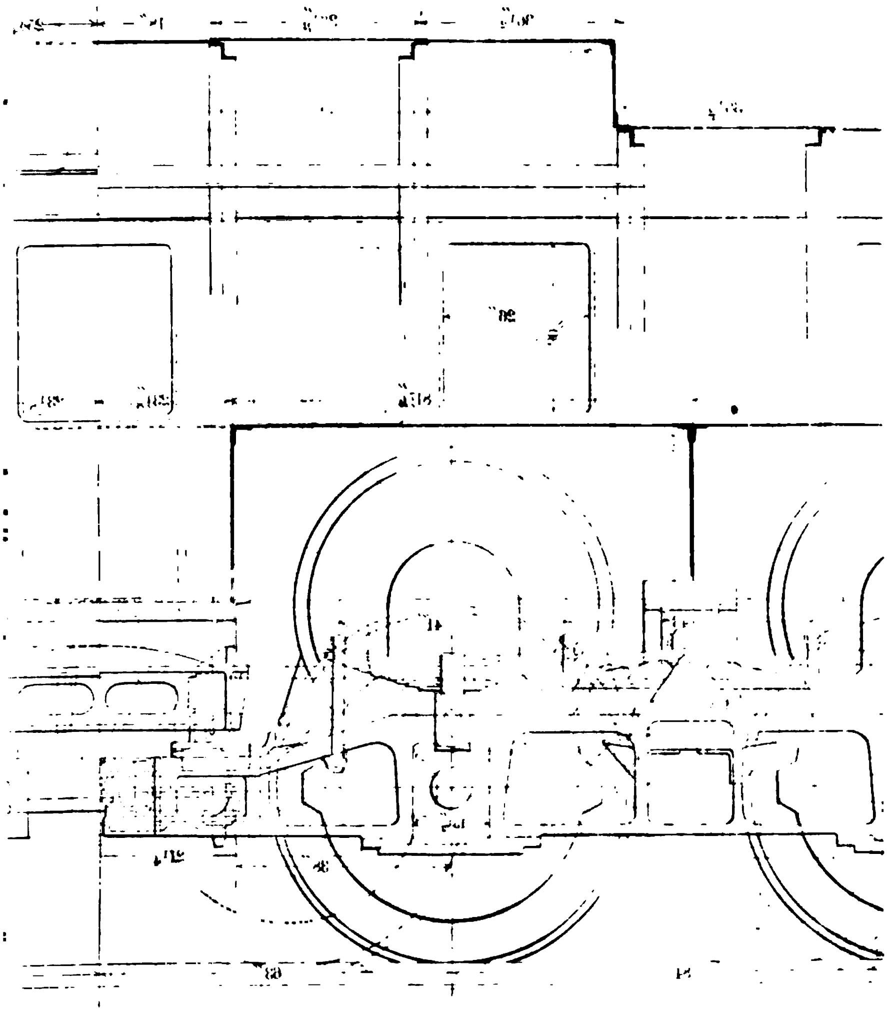
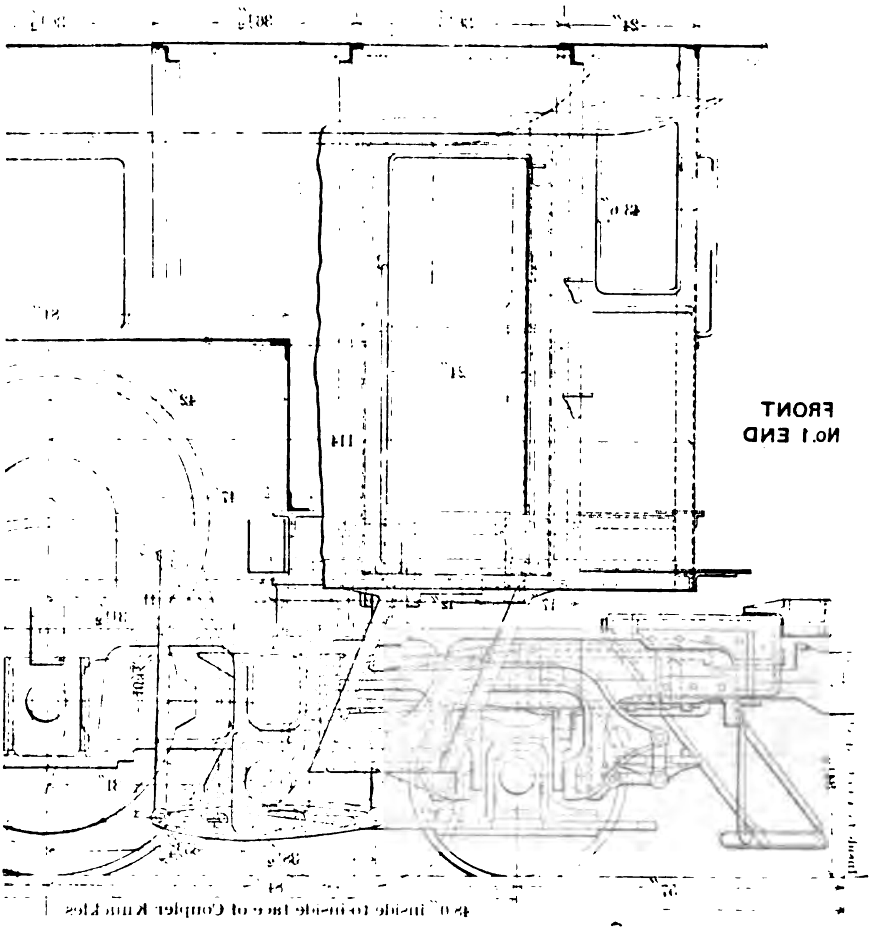


Fig. 40.—Road freight e:



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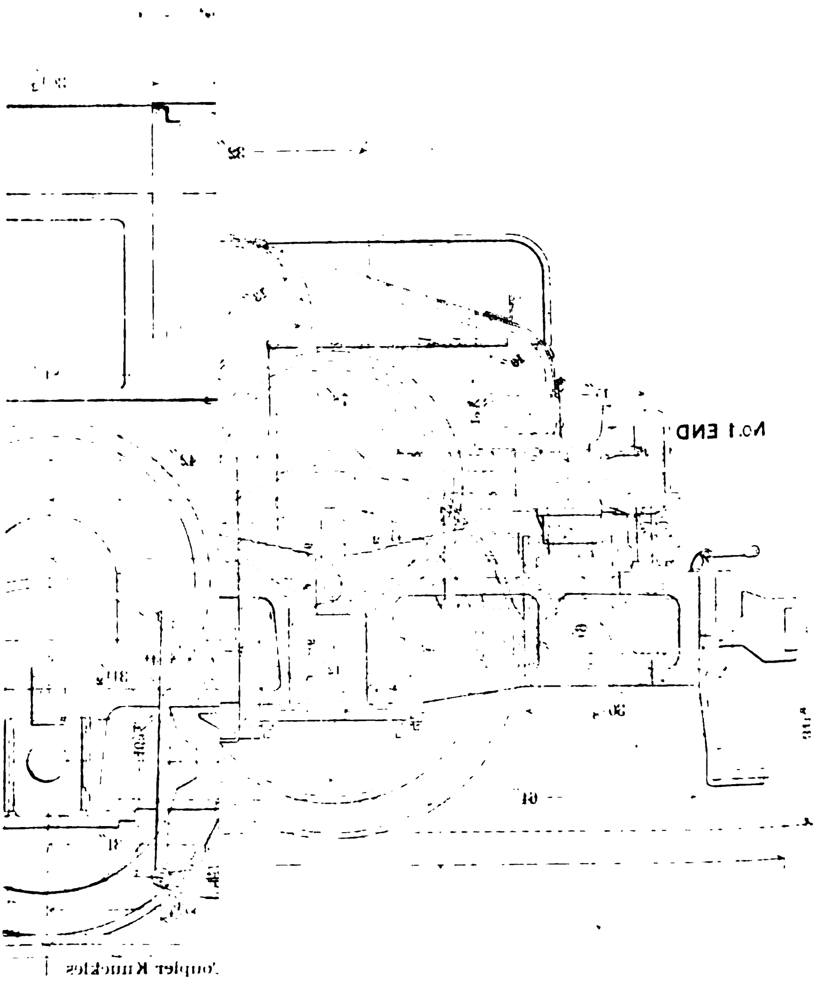
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Coupler Knuckles

for the local service was a wise provision, because at the time the electric service on the New Haven was inaugurated the single-phase multiple-unit equipment had not been sufficiently developed. The future will see the gradual replacement of the locomotives by multiple unit cars for suburban service, and the continued use of the locomotives thus replaced in the express service. Thus, in the event of the extension of the electrification to New Haven there will be a large credit on the work, in that the present locomotives will be used for express operation between New York and New Haven.

Again, these curves (both in express and local service) bring out, through the means of electrical units of power, the track resistances and engine power requirements as were indicated by the steam tests reproduced in the earlier part of the paper.

Space does not permit the inclusion of many drawings or a lengthy discussion of these three types of equipment. Fig. 40 gives an elevation drawing of our most recently designed freight locomotive, the electrical characteristics of which have been referred to in a previous part of this paper. One of the impressive characteristics of this engine is, its ability to start very heavy trailing loads; *e.g.*, 2160 tons. This, the largest load we were able to assemble, was easily accelerated. Such a torque bearing characteristic is of much value under conditions of acceleration on grade, but these figures must not be interpreted to mean that a tractive effort of this character can be sustained, except for a very short interval.

The locomotive is of the quill geared type, entirely spring supported (except wheels and axles), with pony wheels leading and trailing, and four propulsion motors are provided with a normal hourly rating of 396 h.p. each. The speed torque characteristics of the locomotive are shown in Fig. 17.

This type of locomotive is of higher power and differs from our present passenger engine in the arrangement of its apparatus, it being fitted with a central truck over superimposed motors, with the control apparatus arranged in the middle of the cab and a full passage on each side, giving excellent light for inspection of the various items of equipment. This is a marked improvement over the previous type of locomotive, the apparatus and control of which is arranged on the sides of the locomotive with a central aisle.

Besides the above described type of electric road engine, there is being built for the New Haven road two other types of equivalent hauling capacity; one of the side-rod design with two-motor equipment, the other having its power divided between eight motors. Much discussion (pro and con) on various types of engines typified in the above description lead the New Haven officials to a trial of engines of these different designs; all of them being entirely effective for the purposes to which they will be assigned, and at the same time offering a practical investigation into their individual merit, and thus permitting in the end a composite locomotive which will include, as far as possible, all the good principles, to the exclusion of the less desirable.

In connection with the above described locomotives, it is to be remembered also that they have all been designed inclusive of interchangeable operation on alternating current and direct current. In every instance this condition has increased weight and complicated control. A striking example of this is in the complete freedom from complication by the elimination of all direct-current considerations in the Hoosac Tunnel electrification. One is immediately impressed with the great simplicity of the single-phase Hoosac Tunnel locomotive when entering its cab immediately after a departure from a New York, New Haven and Hartford engine.

The cause of the above complication has been due to its having been deemed expedient for the handling of our heavier passenger trains that these electric freight road engines be equipped for direct-current operation from Grand Central Station, but fortunately only a few will be required; the remaining locomotives will be equipped for the simple straight single-phase operation and will haul freight trains between Harlem River and New Haven.

Fig. 41 gives an outline elevation drawing of our switching locomotive. This engine is coming to us as this paper goes to press. To the writer, it is the most interesting of all, though small and apparently insignificant. Much of our experience in electric locomotive practice has been of real value in the design of this engine. Like its larger brothers, it too is of the quill spring-supported type. On account of the buffing strains incident to yard work, its framing and the assemblement of equipment is made particularly substantial. The fact that the capacity of its motors (600 h.p., hour rating) will unquestionably measure up, and with considerable margin, to the duties to be imposed upon it, is brought out by the analysis of the steam switching requirements shown in the earlier part of this paper.

Already the Stamford yard (containing 4.2 miles of track) has been electrified, and upon receipt of the locomotive it will be exercised therein for commercial investigation.

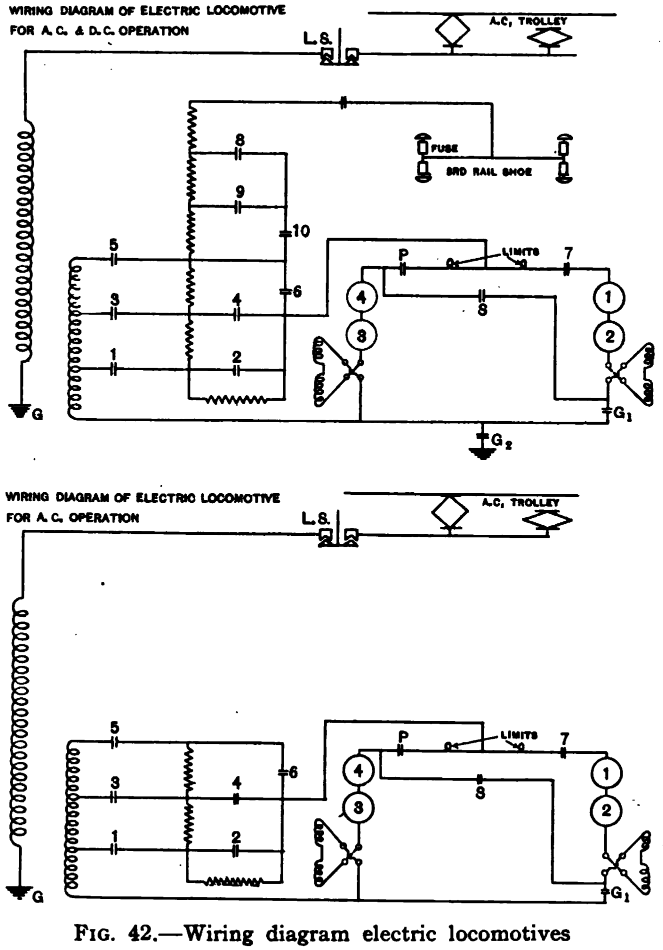
In connection with our alternating-current multiple-unit train development, we have had in operation a multiple-unit equipment consisting of four motor cars and six trailers. Again the requirement of direct-current operation has superimposed upon this equipment the handicap of extra weight and complication of control, and, as in the instance of the locomotives, a careful investigation of the actual requirements necessary has served to reduce greatly these two unwelcome elements. Marked indeed in all types of propulsion apparatus, is the relative simplicity of straight single-phase, over alternating-current-direct-

TABLE 7.

COMPARATIVE WEIGHTS OF ALTERNATING-CURRENT AND ALTERNATING CURRENT-DIRECT CURRENT EQUIPMENTS FOR NEW YORK NEW HAVEN & HARTFORD RAILROAD COMPANY

	Alternating current	Alternating current-direct current
	Pounds	Pounds
4 Motors	31,800	31,800
1 Transformer	7,000	7,000
2 Trolleys with details	1,485	1,485
4 Third rail shoes with fuse boxes		3,200
1 Switch group	1,250	
3 Switch groups		2,700
2 Reversers	400	400
1 Line switch	585	585
1 Set grids	480	1,800
Bus line receptacles and jumpers	75	75
Train line receptacles and jumpers	100	175
2 Master controllers	100	150
Limit switches and line relays	60	80
Battery and charging set	325	325
Pneumatic and insulating details	90	100
Main switch		40
Wattmeter		40
Changeover switch		200
Cables	750	1,500
Blower outfit	800	800
Tablet board and lighting details	450	450
Erection details	1,500	2,500
	47,250	55,405

current equipment. Weight is bad enough, but complication is worse. Great strides have been made in the simplification of the alternating-current-direct-current apparatus, but even with all of this, it is interesting to note the comparison between weights and control for the two classes of equipment. In table 7 herewith, it is to be noted that the straight single-phase equipment is over 8000 lb. lighter than the alternating-current-direct-current equipment, and in the diagram of connections Fig. 42 it is to be noted that the number of unit switches for the alternating-current-direct-current control are 100


WIRING DIAGRAM OF ELECTRIC LOCOMOTIVE FOR A.C. & D.C. OPERATION

WIRING DIAGRAM OF ELECTRIC LOCOMOTIVE FOR A.C. OPERATION

Fig. 42.—Wiring diagram electric locomotives

per cent greater than those of the straight single-phase. To the previous multiple-unit equipment mentioned there will be added (now under construction) four motor cars and twelve trailers. These, unfortunately, again will have to be equipped for interchangeable alternating-current-direct-current operation. The equipments, however, to be ordered in connection with the Harlem River Branch electrification and the New York Westchester & Boston electrification will be free from the intricacies necessary to this dual service, these latter equipments, together with the freight and switching engines, being of the straight single-phase design.

GENERAL CATENARY CONSTRUCTION

In the simultaneous authorization of the electrification of the six-track Harlem River Branch for freight and passenger operation, the New York Westchester & Boston and the Hoosac Tunnel, it naturally made it imperative for the engineers of the New Haven Road to prepare a very extensive set of plans to cover completely these three constructions. Illustrative of the flexibility and adaptability to standardization of the single-phase system, while the Harlem River six-track work required a longer and stronger bridge than the four track New York Westchester & Boston railroad, the general design of both, however, are the same; and notwithstanding the difference in number of tracks, the wire plans for the overhead catenary system of the four-track were applicable to the six-track, the simple addition of two tracks merely meaning an additional 50 per cent increase of material and an equal percentage of weights and stresses for the bridges to sustain.

Space does not permit a lengthy discussion of the general drawings and plans that have been presented in this paper. Owing to the necessary reduction, in reproducing the tracings, the figures on the illustrations and particularly those of the strain and deflection tables, have been reduced to sizes which are difficult to read, without the aid of a glass. However, in including these drawings, my thought was that they would be an epitome of the extensiveness of the work under way, and give some idea of the methods involved in its general specification.

It will be of interest, no doubt, to state that in all the New Haven electrification drawings, it has been the attempt to make each one, while descriptive of the construction desired, at the same time a specification of procedure in erection.

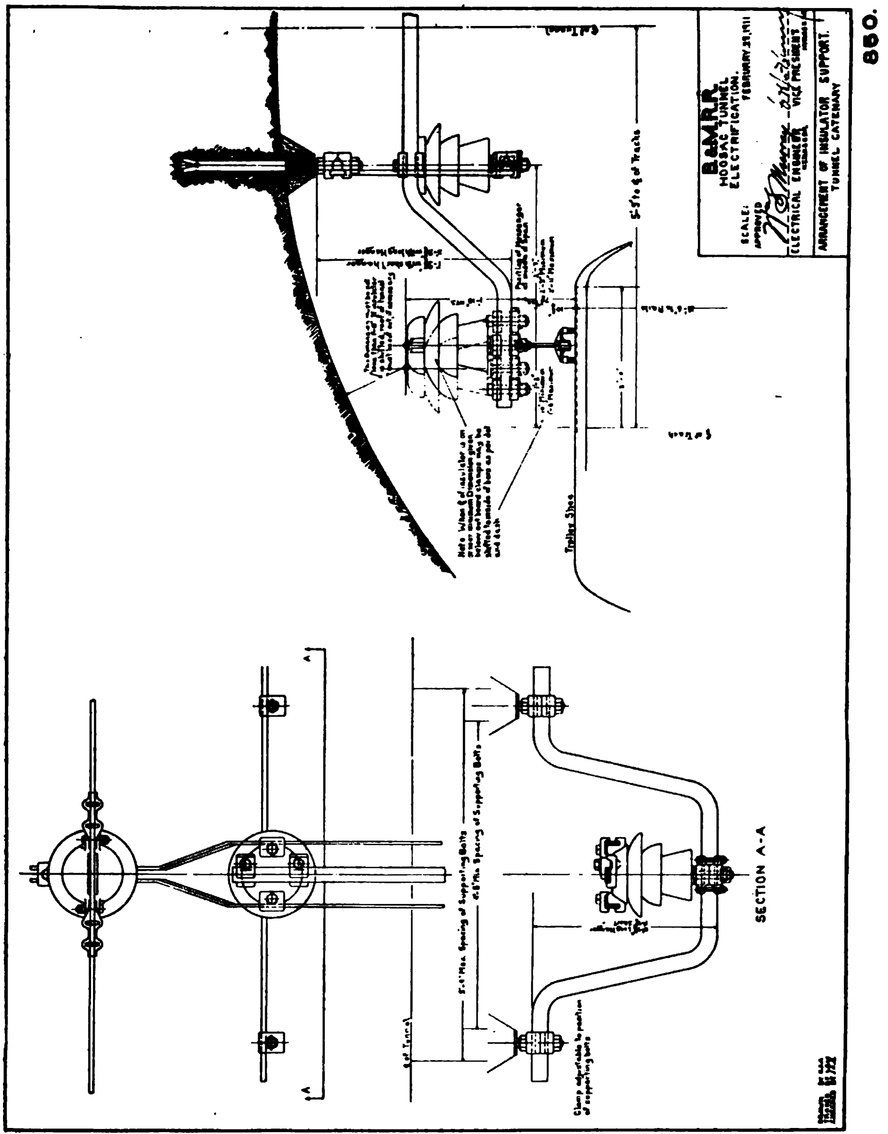


FIG. 44.—Hoosac Tunnel catenary bracket

against any breakdowns between the electrified wires and ground.

From the crown of the tunnel is suspended a bracket, as shown in Fig. 44. Four insulators, each capable of resisting 150,000 volts to ground, are installed on this bracket. Two of these insulators apply to each track. Their arrangement of support is such as to place them in series, thus giving them a combined dielectric strength of 300,000 volts. The outside insulator holds the track messenger, to which is pendent the contact wires below. Some criticism might be offered in using a 150,000-volt insulator, where 40,000 might have sufficed. By the expenditure of $1 more per insulator, there was secured practically eight times the insurance from breakdown. The tunnel is five miles long—an unhandy place to come to a full stop. There are 1000 insulators; hence $1000 has been spent to secure eight times the protection.

On the approaches to the tunnel, insulators of the design as shown in Figs. 45 and 46 are used. The opportunity here seemed an excellent one to secure immunity from trouble; 50 cents extra per insulator secured practically three times the protection offered by an ordinary 40,000-volt insulator. The outside insulators before erection are all required to withstand a dry voltage test of 110,000 volts.

It has been forcibly impressed upon the writer that it is good engineering to spend money on insulation. All of the insulators purchased for the Hoosac Tunnel electrification, inclusive of the tunnel itself and its outside approaches, did not total one half of one per cent of the total expenditure. *Insulation* is of all things the one most important thing to be right, in order to secure continuity of service. It pays a handsome dividend every year. It has been said by our electrical superintendent, Mr. H. Gilliam, that the emergency train service on the New Haven electrified lines would practically cease if line failures were eliminated. This means that mechanically everything is fit. There is no reason why the electrical condition cannot be made identical.

So much with reference to our plans of main line electrification, in which I believe there can be recognized a general sense of inherent standardization, notwithstanding they refer to three properties with a variety of service and location.

In a previous part of the paper the electric switch engine has been referred to. Figs. 47 and 48 show two great yards on the

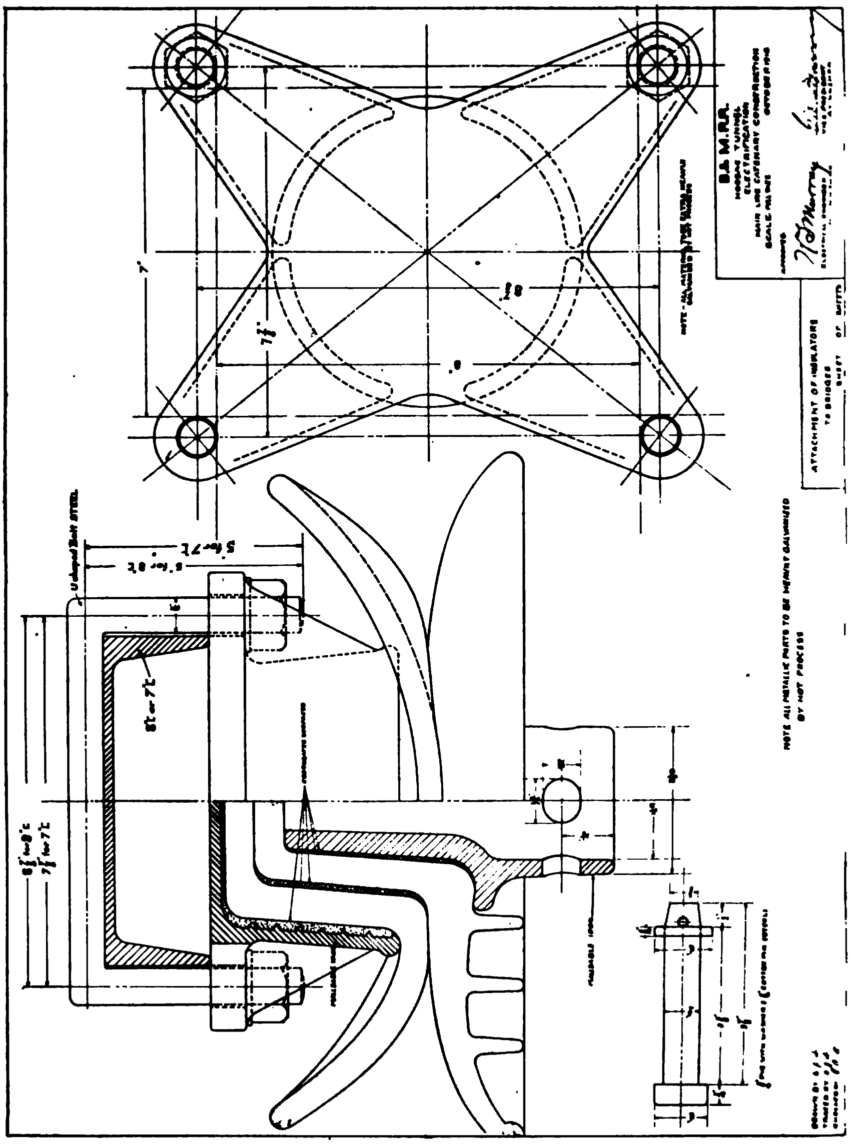


FIG. 45.—B. & M. Main line insulator

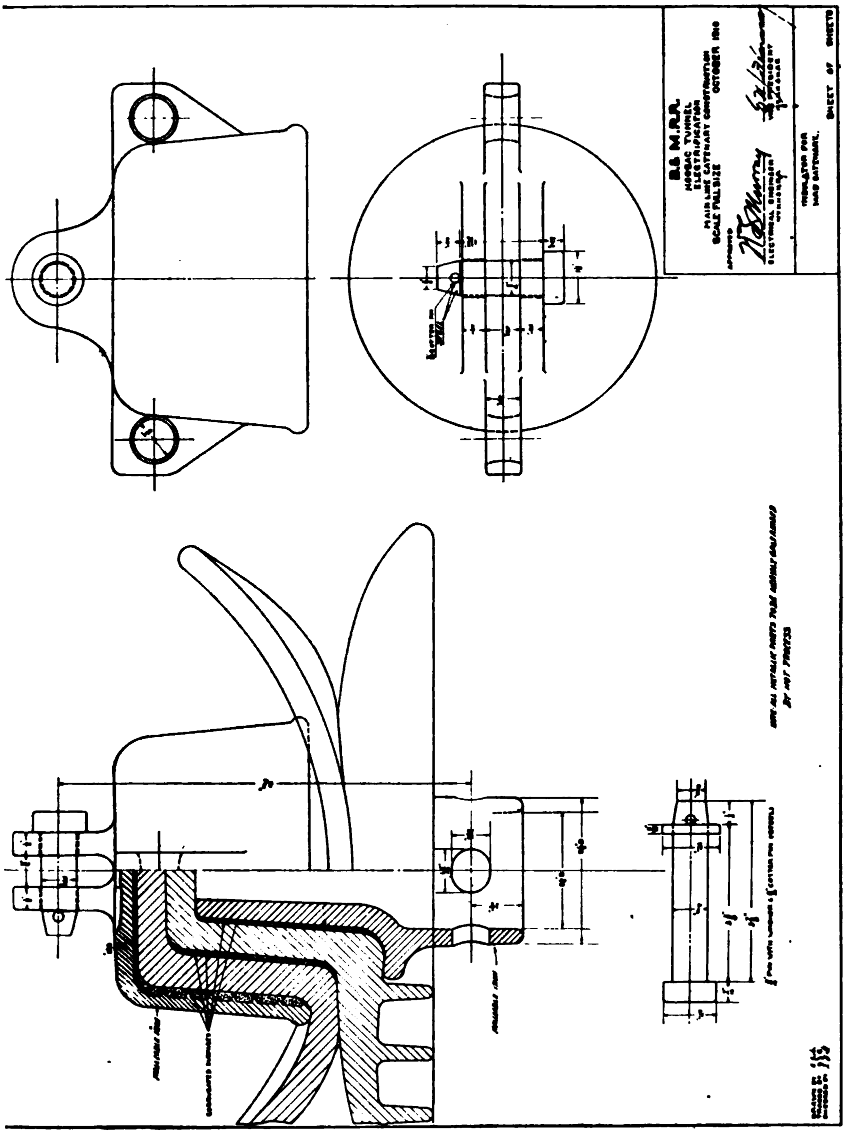


FIG. 46.—Hoosac Tunnel. Insulator for yard catenary

Harlem River branch; one of them covering 20 miles, the other 42.3 miles in tracks that are being electrified, and in which the electric switch engines will work.

On account of the extremely small amount of current required per horse power developed, and on account of the excellent conductor section offered in the gridiron arrangement of the track yards, not a pound of copper is required throughout this extensive trackage, with the exception of rail bonds and these are reduced to the smaller size and only one rail is bonded, with the attendant result of an extremely low cost, compared to main line construction. Fig. 49 gives a cross section at station 22+81 ft. Harlem River yard, from which is to be noted the simplicity of cross catenary span for the support of the track contact wires. On this drawing is seen the same cross catenary wire split up into spans supporting contact wires over tracks, some with regular—others with irregular spacing; the irregular spacing being due to the leading in of tracks to a common ladder. By a simple system of bridles, which on the plans are to be noted require only one rigid post to hold many tracks, the overhead contact wires are held in proper alignment over the tracks they serve. The cost of yard electrification, as before stated, can vary from $1,500 to $3,000 per mile of track, depending upon the average number of tracks spanned.

ELECTRIFICATION COSTS

The question of cost, both with reference to capital investment and operating in connection with electrified lines, is naturally the greatest factor of consideration on the part of railroad companies contemplating the application of electricity to their lines. In this department I am quite in agreement with the previously scorned adage—" Every situation is a study in itself "; for while in my opinion no trunk line electrification can be better served than by the use of single-phase current, it must be conceded that electrification costs must vary with the greatly fluctuating conditions of volume and density of traffic involved. Again, while it would be perfectly possible to state the actual cost involved in handling a train mile by electricity *vs.* a train mile by steam, this information as applying to the New Haven road might be extremely misleading when considered for other application. It is not to present any information not generally known, to say that power houses can be constructed, depending upon the capacity, from $90 to $110 a kilowatt; line construction for

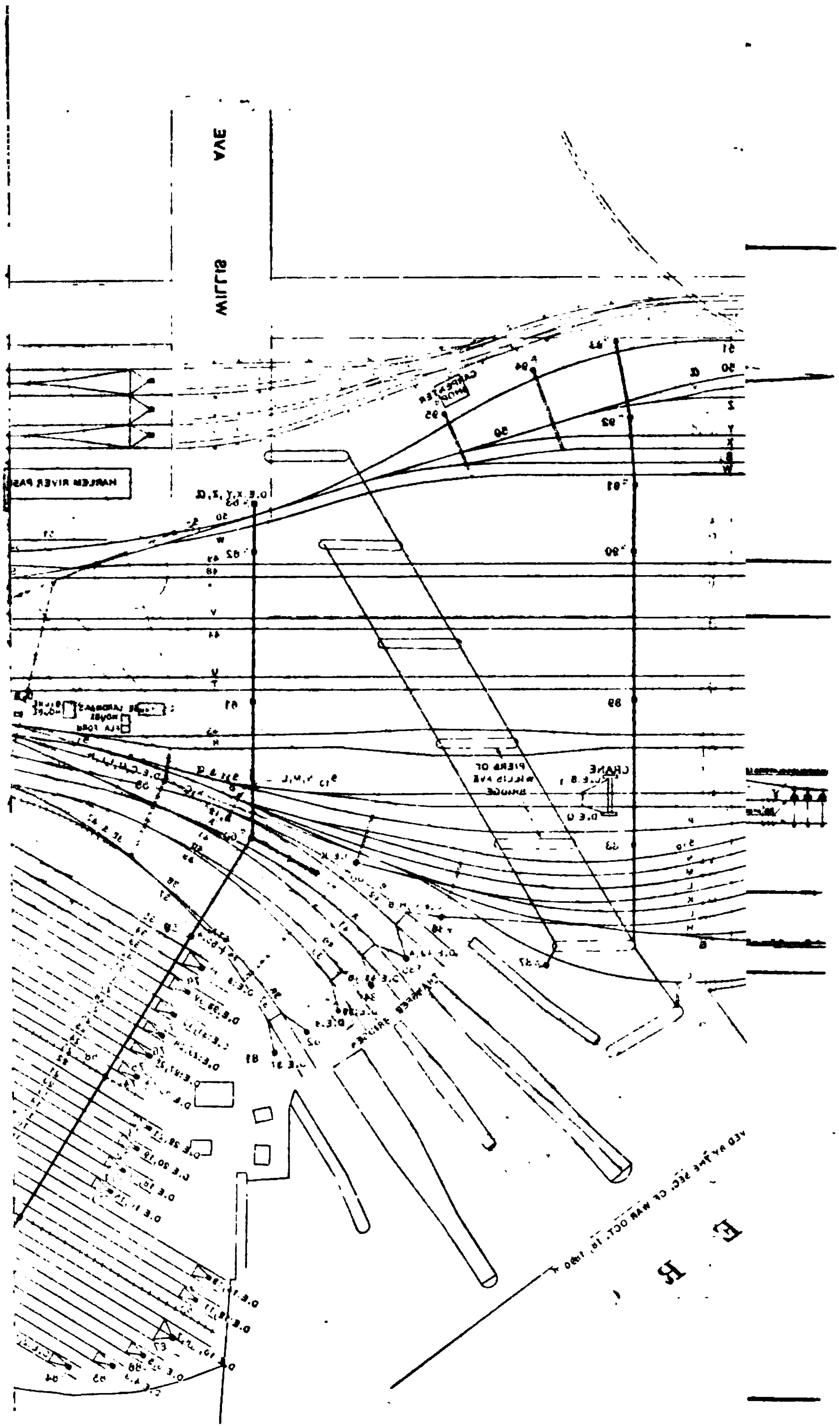
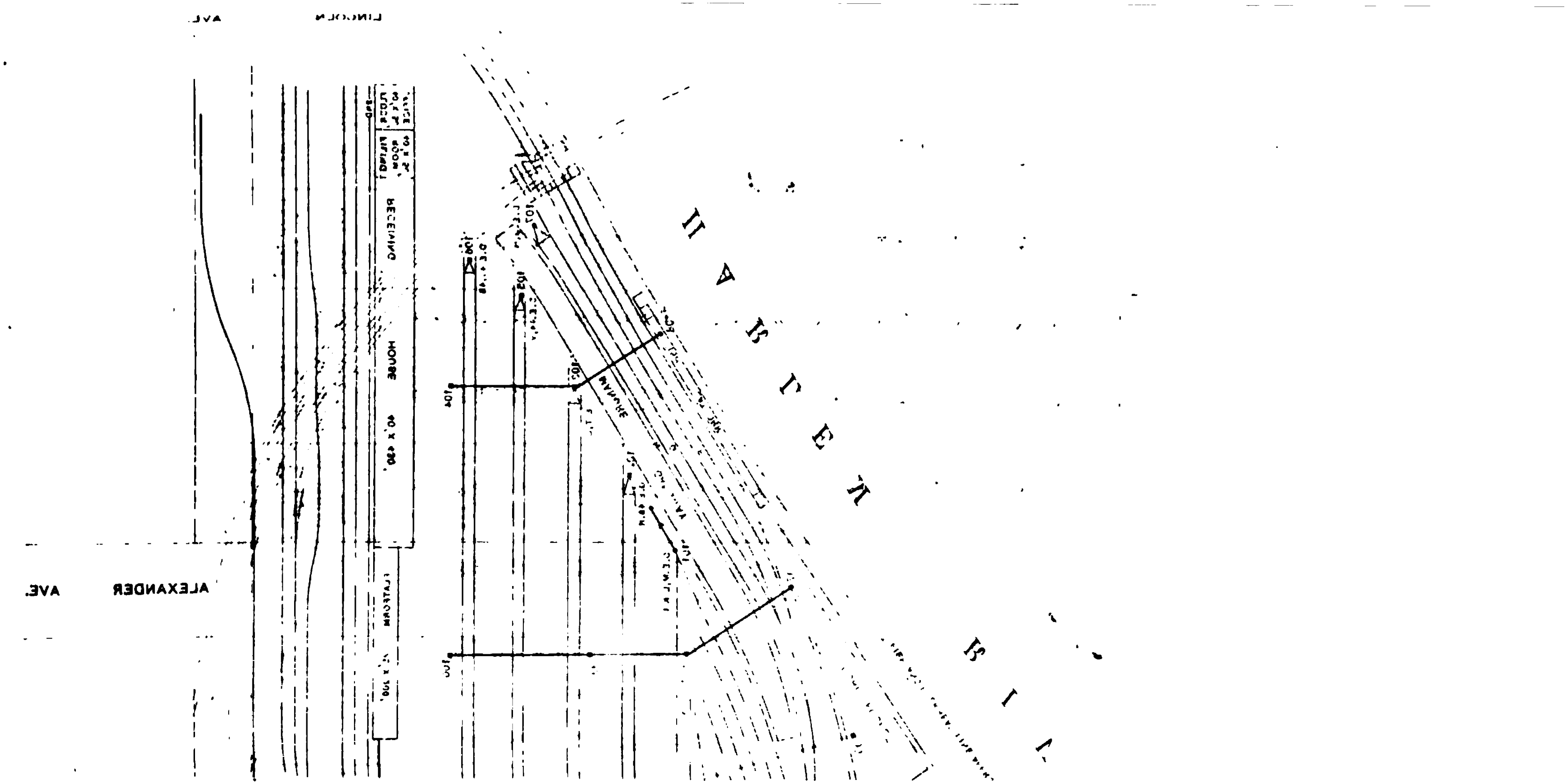


Fig. 47.—Harlem River Yard Layout


ALEXANDER AVE.
LINCOLN AVE.
RECEIVING HOUSE 40' x 430'
PLATFORM 25' x 200'
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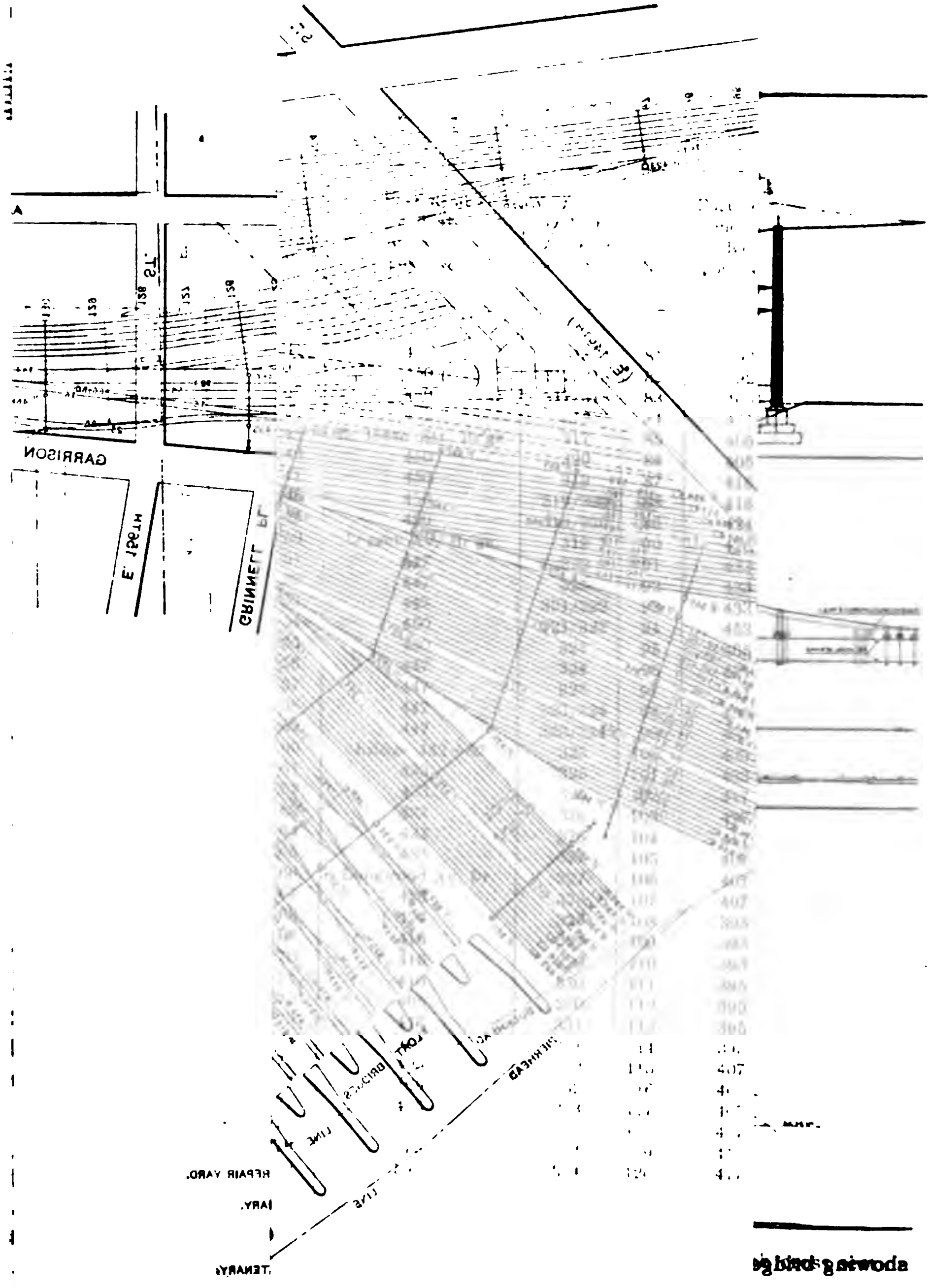
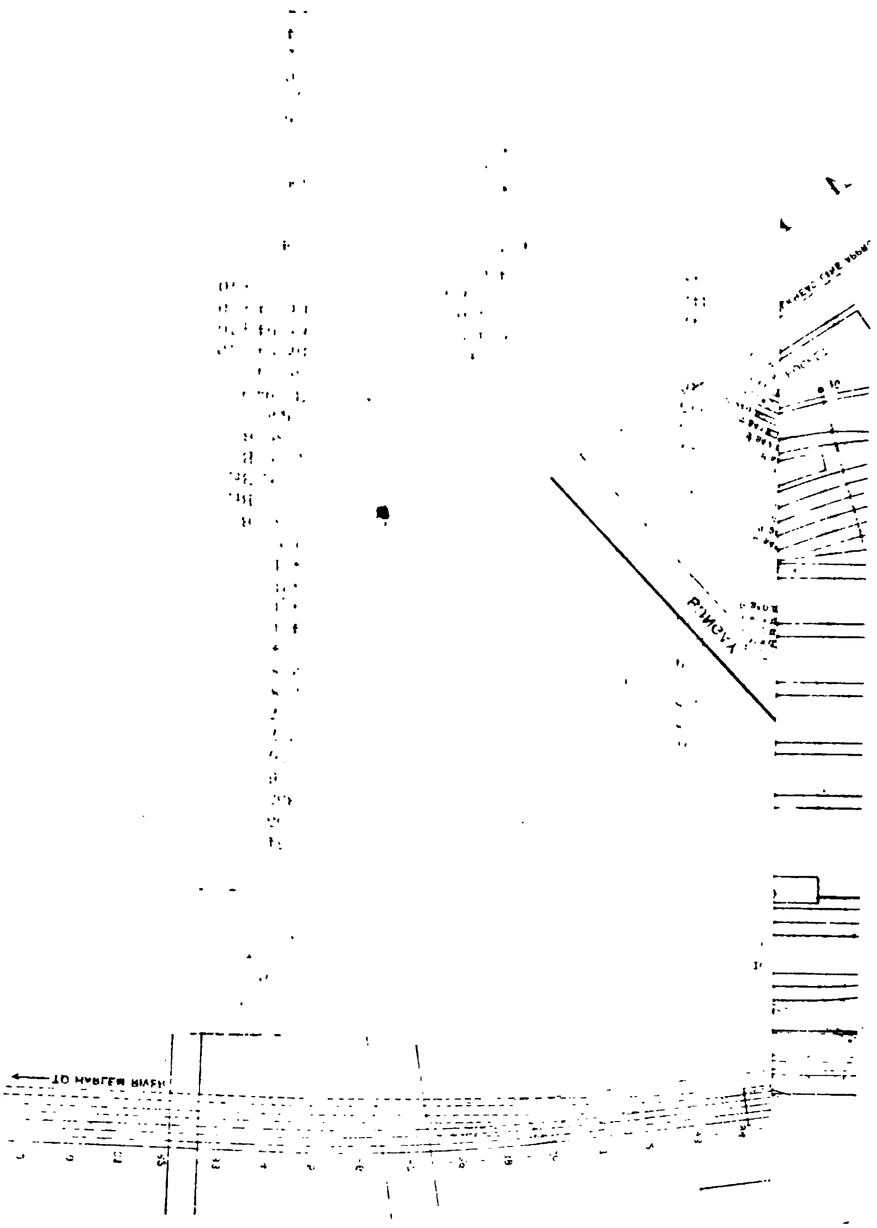
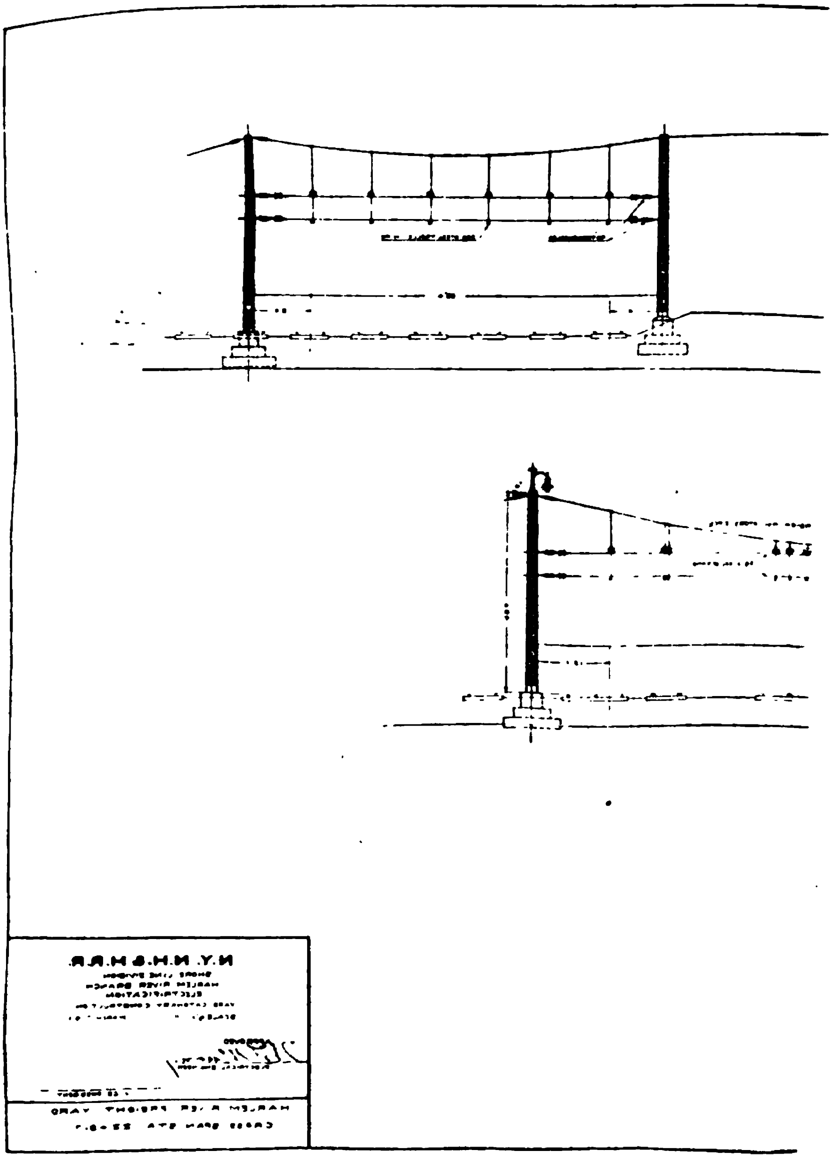



TO HARLEM RIVER



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(Murray 1440)

showing bridges and foundations

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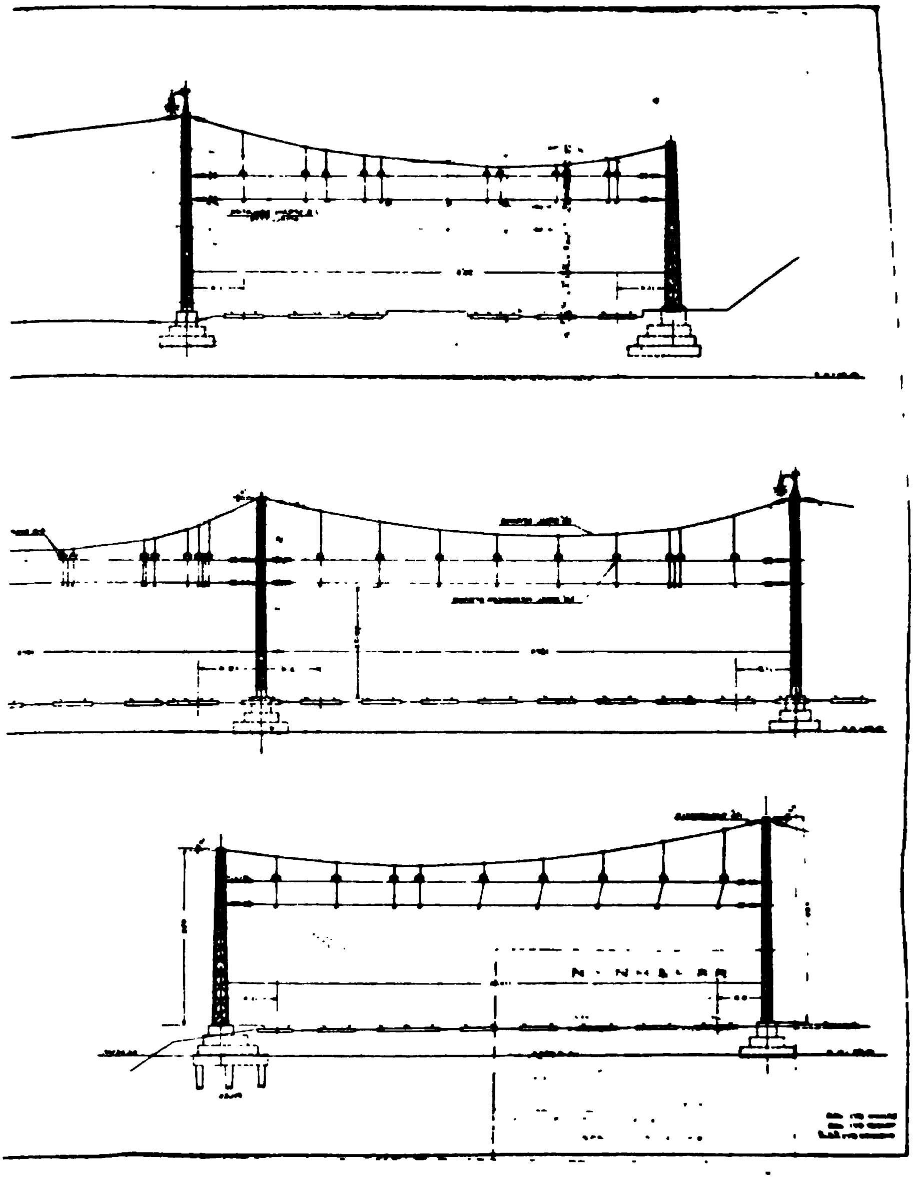


Fig. 49.—Harlem River Branch cross section

one, two, four and six tracks can be erected at costs varying respectively from $4,000 to $7,000; from $8,000 to $15,000; from $25,000 to $40,000; $40,000 to $60,000 a mile; the fluctuation in cost for these respective constructions depending entirely upon the standards elected, which are inclusive of the consideration of importance of track, in turn bringing into consideration the advisability of wood and steel post construction, cross catenary and bridge span construction, single or compound catenaries, etc., also the cost of overhead yard construction can vary from $1,500 to $3,000 a mile, depending upon number of tracks spanned and type of construction selected.

Locomotives of the passenger road and switching type, depending upon the nature of their service, can vary in cost from $25,000 to $45,000 a unit. Thus it is seen that it would be impossible, from the capital point of view, to give a useable estimate of electrification cost. Again the necessity of property acquisitions, which in one case may be nothing and in another a very large sum, all varying in accordance with the environment of the electrification in question, make such studies individual to the specific cases under consideration.

In general, from an electrical operating standpoint, it may be stated that for trunk line properties, where a very considerable density of traffic is involved, there will be shown a considerable debit in the department of " maintenance of way and structures," while in the departments of " maintenance of equipment and transportation expenses" a large credit, if the proper system is selected, may accrue. The balance between the debit and credit columns furnishes the ground upon which it may be said it is either a good or bad investment for the railroad company to electrify; and yet even though the direct returns prove unsatisfactory, it does not follow that the investment is a bad one if considered from a broader standpoint of general policy.

A most careful analysis of the relation between steam and electricity was made in connection with the lines of the New Haven road west of New Haven. I have no authority, in presenting such a paper as this, to state whether the policy of the railroad company in electrifying over 300 miles of its trunk line rails, terminals and yards was for financial gain to itself or better service to its patrons; but at least it is reasonable to assume that with an application of electricity to cover complete passenger and freight train propulsion and yard switching over the mileage above named, expending millions of dollars to effect such a service, its Directors could not have ratified the extension of the adopted system and its application over such a wide territory in all classes of service, unless the successful and uncompetitive characteristics of the system were not immediately apparent.

Not until the electrical system of the New Haven road is a unit in itself, rather than a mixed service of steam and electricity, can its true economies of electrical traction be discussed. Suffice it to say that the two great departments of economy lie in the saving of fuel and repairs to rolling equipment.

I regret that my contribution in this paper to the many times repeated question as to the cost of electrification cannot bring a definite reply to each request. The electrification of railroads will not await the reply of an impossible inquiry. The practical answer, and substitute for this inquiry, is: As electrification of trunk lines is now practically at hand, what is the correct system for all? Our experience with the single-phase system as applied to the New Haven Road to over 300 miles of its track, with the necessary extension to follow to New Haven, adding 150 more—making a total system, with yards, of nearly 500 miles, may offer a strong suggestion in this direction.

Recommendations. As in the early days when alternating-current application forced its way into the acceptance by its very opposers, so has the force of its application to the trunk line railroad problem impressed the writer that he has not felt it necessary to make any plea for its acceptance. When railroads consider trunk line electrification, all important will be the matter of freight movement and with it the cost and convenience of operation of their yards. The ratio of the mileage of yards in the division run between Harlem River and New Haven to the main line tracks, is over 55 per cent; and while the New Haven road may be considered to have a high ratio of yard mileage to main line mileage, this condition is ever true throughout the railroads of the Atlantic Coast territory. In fact, such a condition is naturally true of any territory including cities and towns of close proximity to each other. In writing this paper, it has been my effort to avoid a discrimination between systems. I wish, however, to state very plainly that I am not at all in sympathy with the attitude on the part of some who claim some recognition in the field of railroad engineering, when they suggest the advisability of not advocating any particular system of electrification. To discuss electricity *vs.* steam without a recommendation of system in the specific cases of trunk line work, in my judgment, is to launch a ship upon a rough and windy sea without a rudder. I plead guilty to a considerable effort in trying to lay before the Institute the facts presented in this paper. I have endeavored to deal with nouns and not adjectives. An extremely important matter would be omitted if I did not say that my experience with the single-phase system *vs.* other competitive systems, affords me the sincere conviction that, under practically all conditions of trunk line consideration where the traffic is of the same amount and character, or indeed much less than that which is comprehended in the mileage that this paper covers, its first cost is at the greatest not more than 85 per cent of its next best competitor, and its operating costs less than the above percentage.

The above statements should not be taken to mean that all trunk line railroads, considering electrification, can electrify and save money; indeed its general application is prohibitive. There are, however, roads that must and will electrify. To such railroads it is my hope that the information compiled will be of value.

It has been suggested by some not altogether friendly even now to the single-phase system, that if this paper be made inclusive of specific recommendations as to system to be applied for trunk line properties, inclusive of suburban and terminal territory, that it might confuse the mind of the railroad man, due to diversity of opinion among electrical engineers on this subject. I wish to say, with reference to this matter, that my opinion of and respect for the railroad man, born of the past six years of intimate association with him, be he an executive of finance, transportation, operation or engineering, is that he is not of the caliber to be confused by a discussion of this subject. I have invariably found rudders on their ships; why not one to ours? And let me assure those who are contrary to this opinion that railroad men can intelligently analyze any argument that is to be advanced—pro or con—on this highly necessary and near decision. The paper, however, is not presented to precipitate an argument; nor is it an argument for the single-phase system. Statistical records of the first cost and operating expense make such a course unnecessary. It has been written with the purpose of placing in the hands of those interested in the electrification of railroads the facts concerning the application of single-phase current to nearly 500 miles of trunk line property and to make a specific recommendation that for the sake of simplicity and economy it be the adopted system for other trunk line properties which the future will see electrified.

I wish to here acknowledge the able services of Mr. Paul Real, my principal assistant, in connection with the preparation of this paper.

APPENDIX

The following illustrations (Figs. 50 to 76) include the detailed drawings pertaining to the overhead catenary construction for:

1. New York, New Haven & Hartford Harlem River Branch.
2. New York Westchester & Boston Railroad.
3. Hoosac Tunnel Electrification.

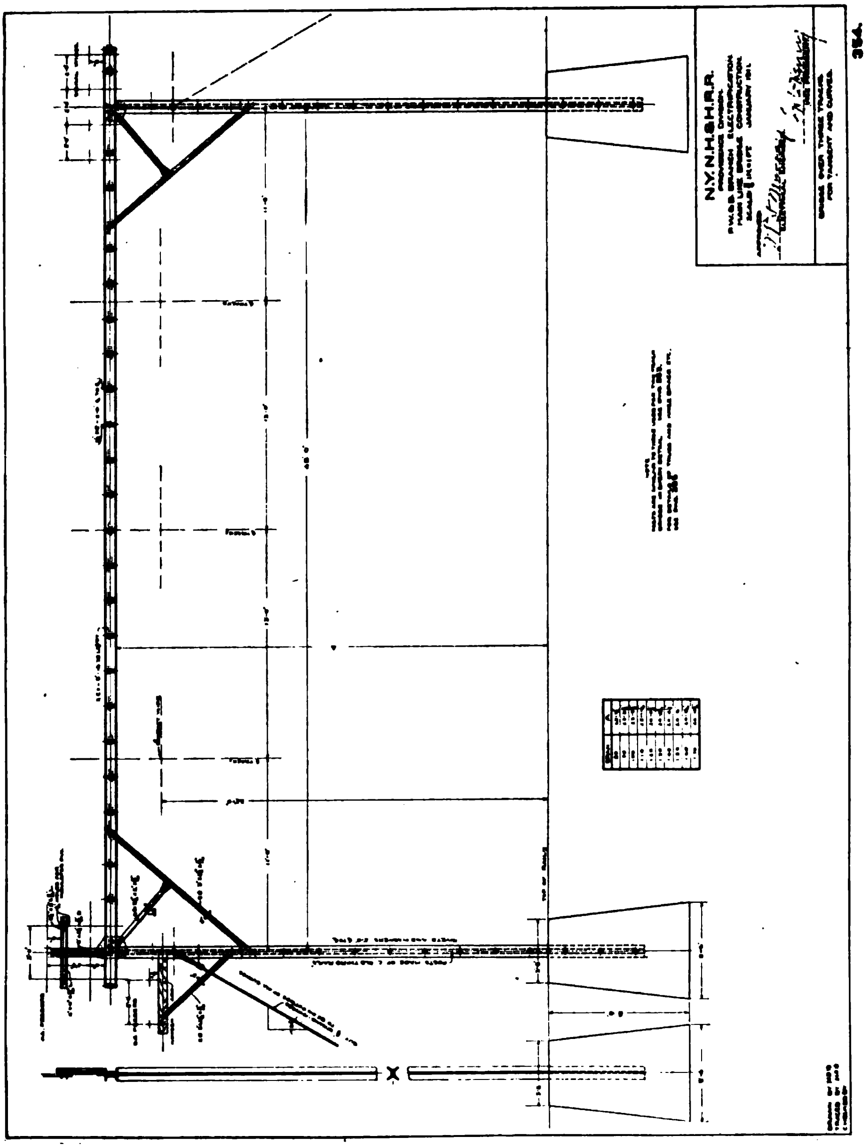


FIG. 50.—P. W. & B. branch three-track bridges

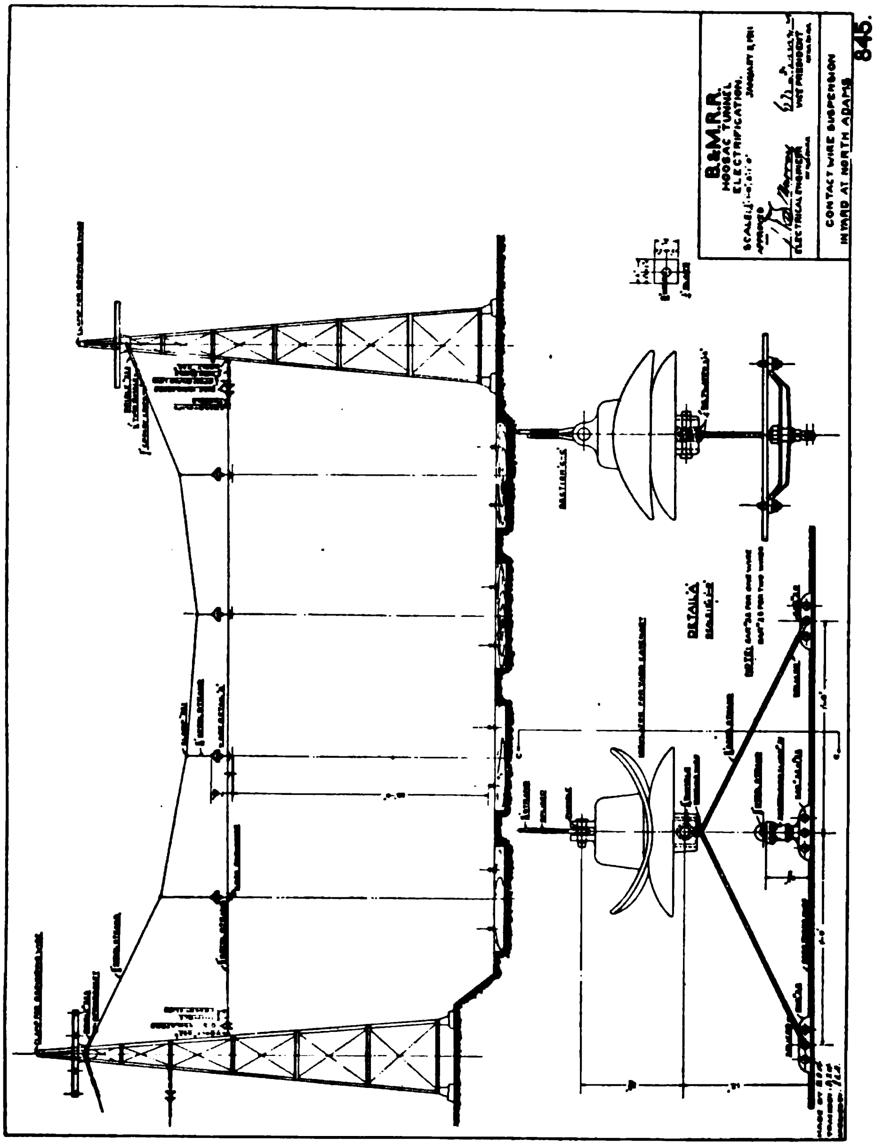
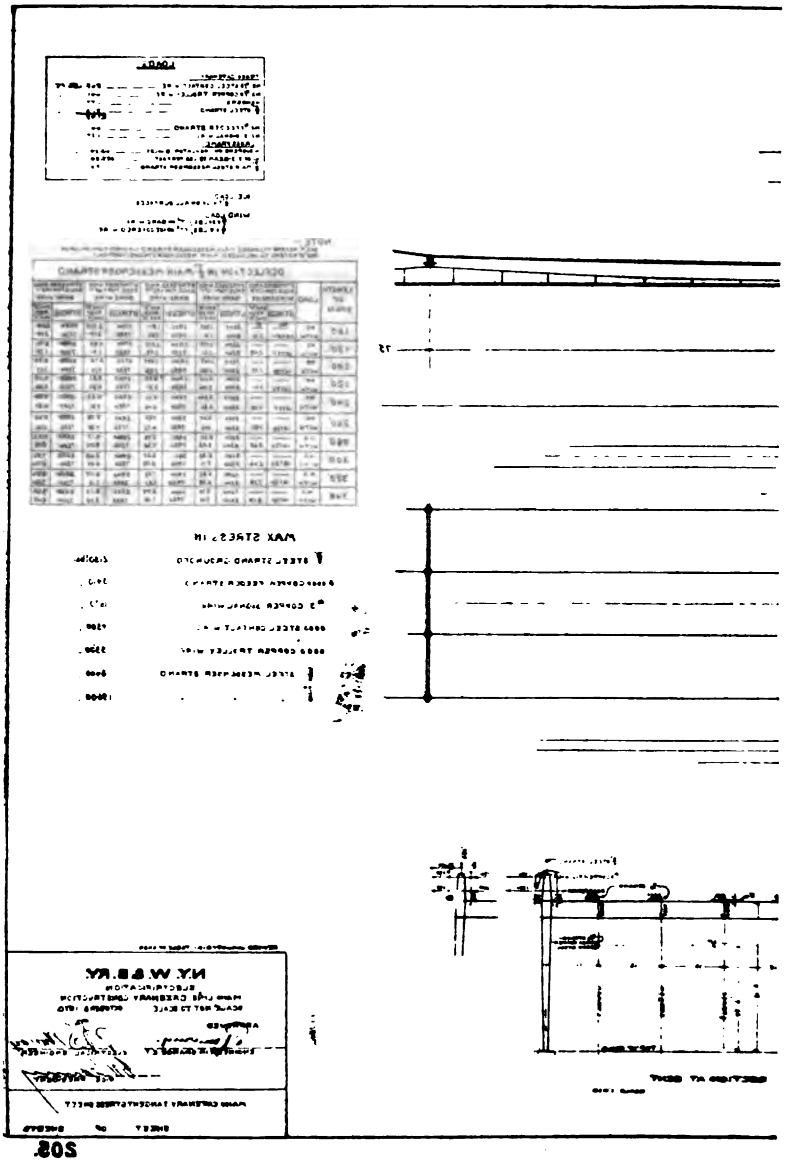


FIG. 66—Hoosac Tunnel yard construction



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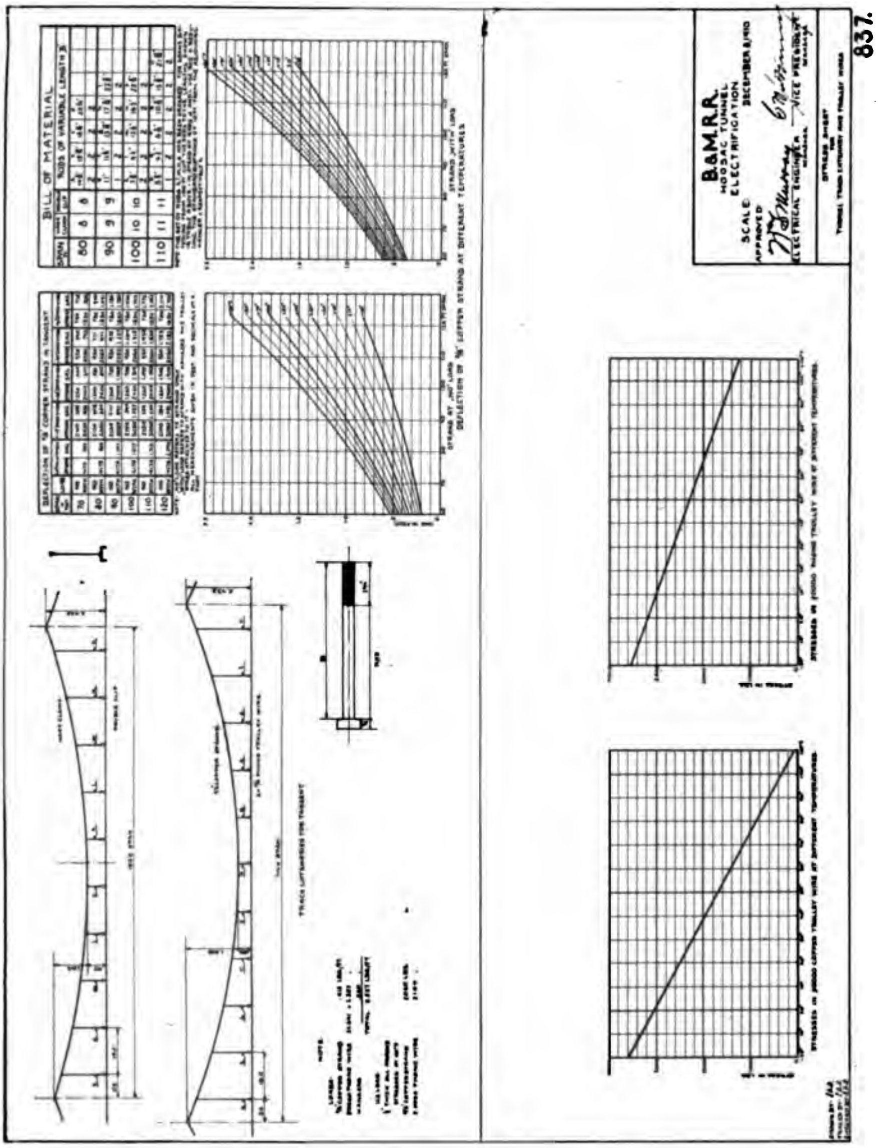

FIG. 67.—Hoosac Tunnel stress sheets for tunnel track catenary and trolley wires

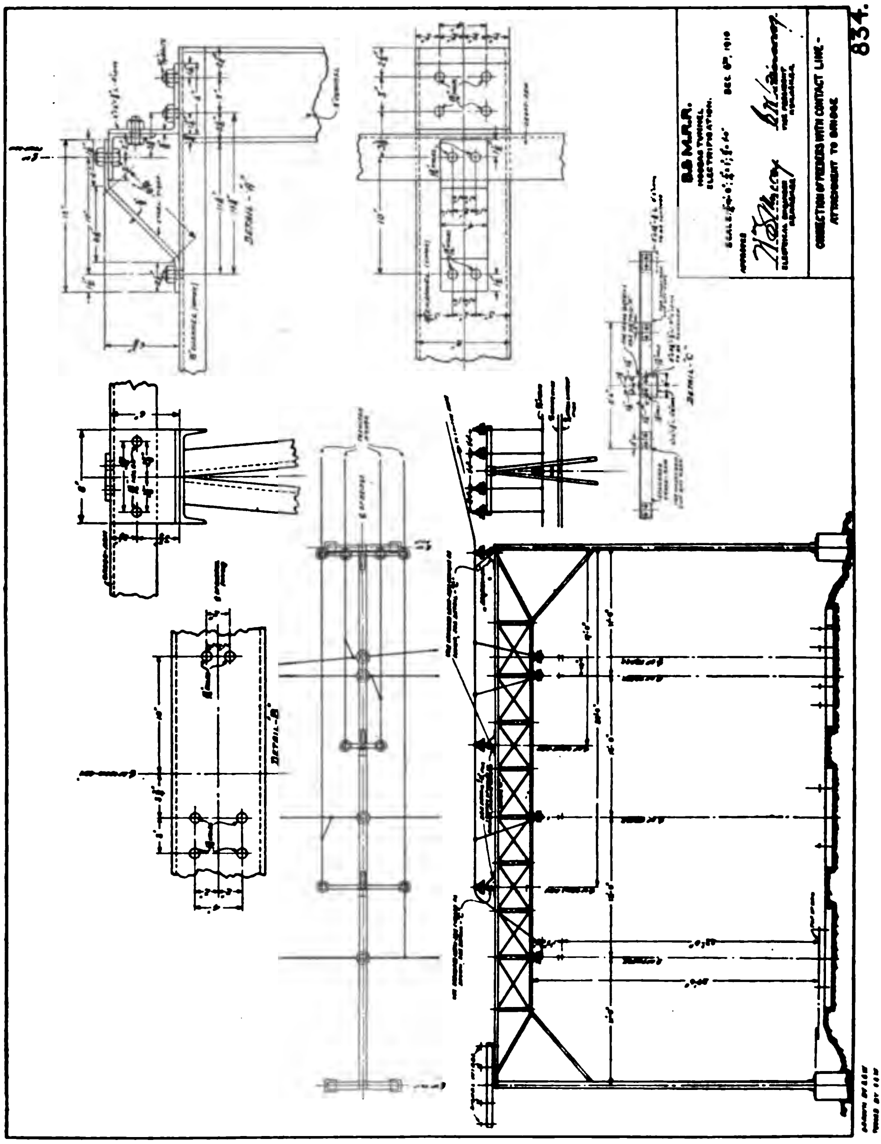

FIG. 68.—Hoosac Tunnel method of connection to contact lines

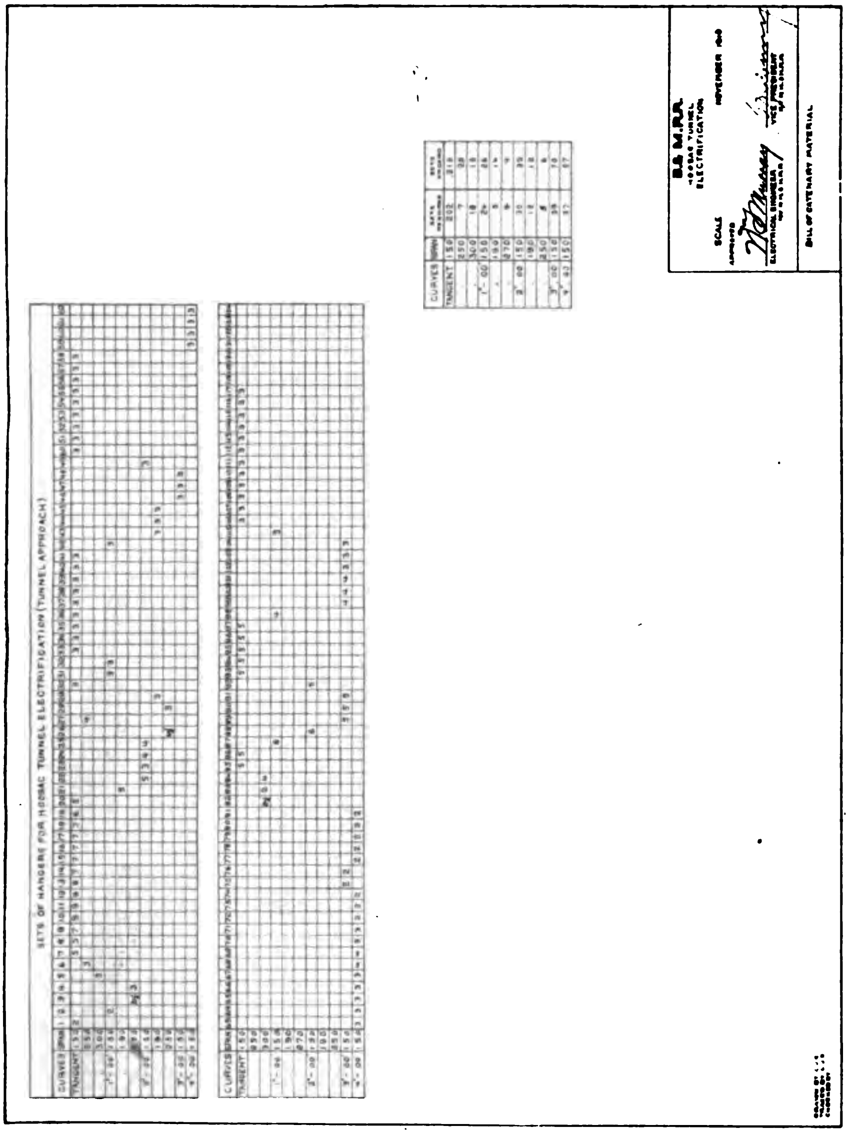

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FIG. 69.—Hoosac Tunnel bill of catenary material

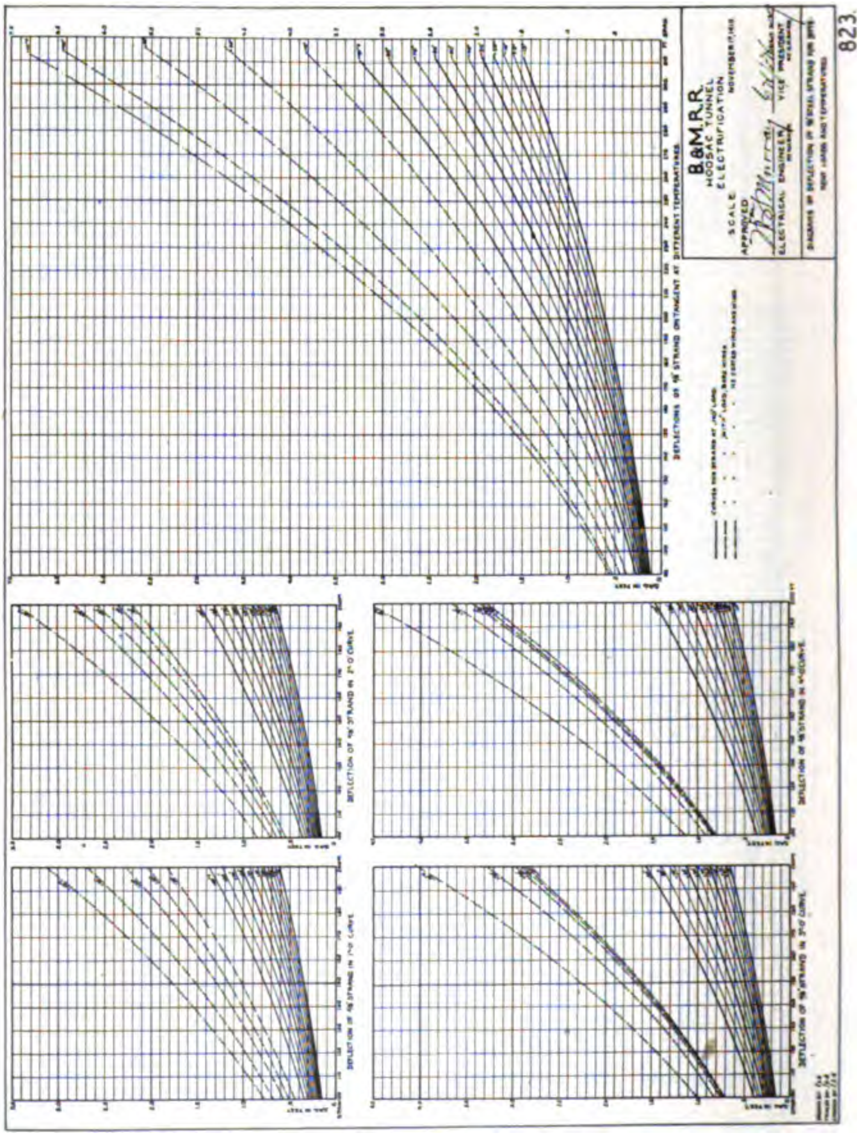


FIG. 70.—Hoosac Tunnel deflection sheet for different loads and temperatures

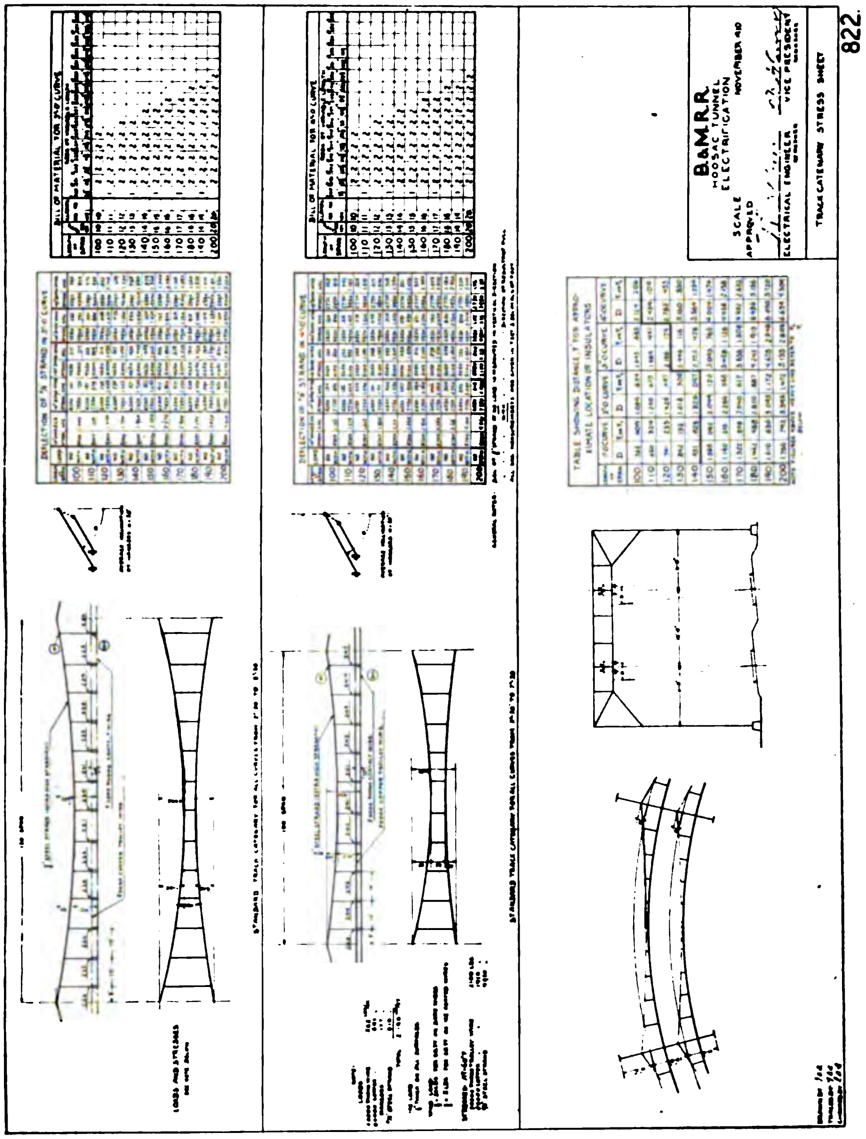


FIG. 71.—Hoosac Tunnel track catenary stress sheet

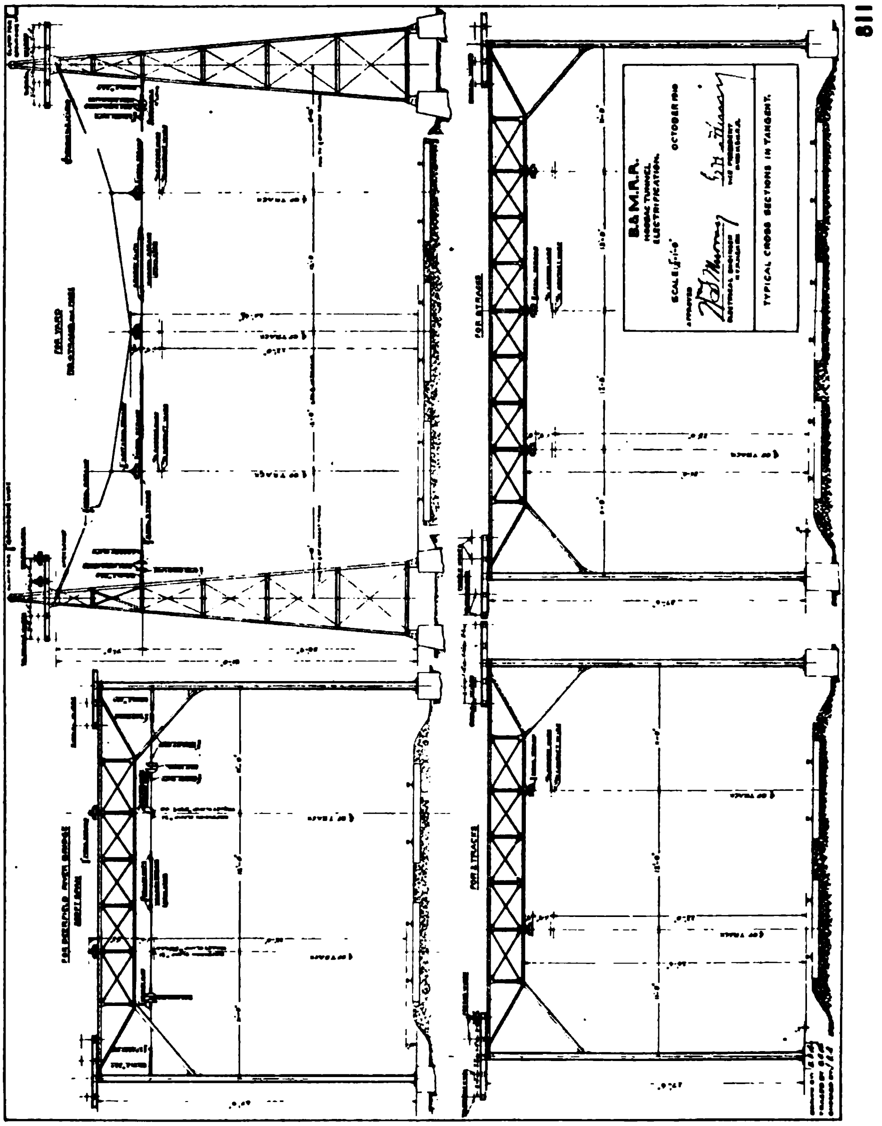


FIG. 72.—Hoosac Tunnel cross sections in tangent

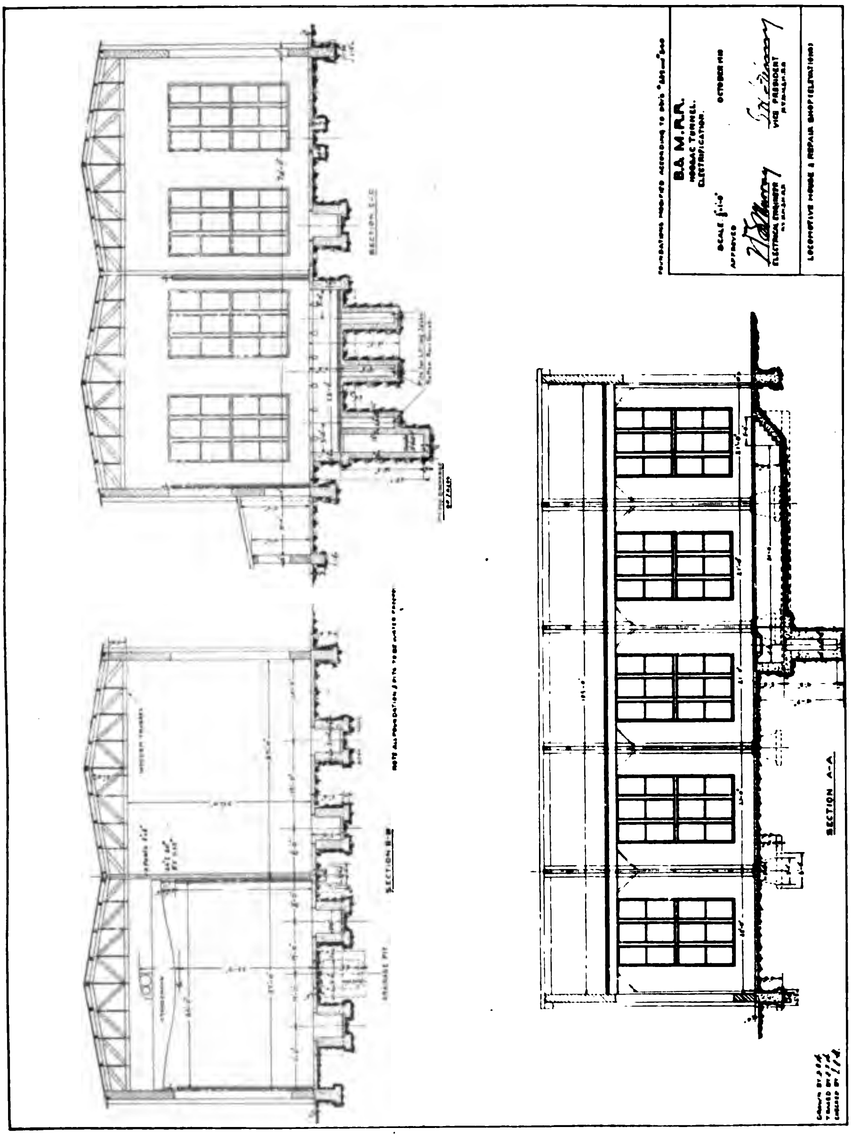


FIG. 73.—Hoosac Tunnel locomotive repair shop

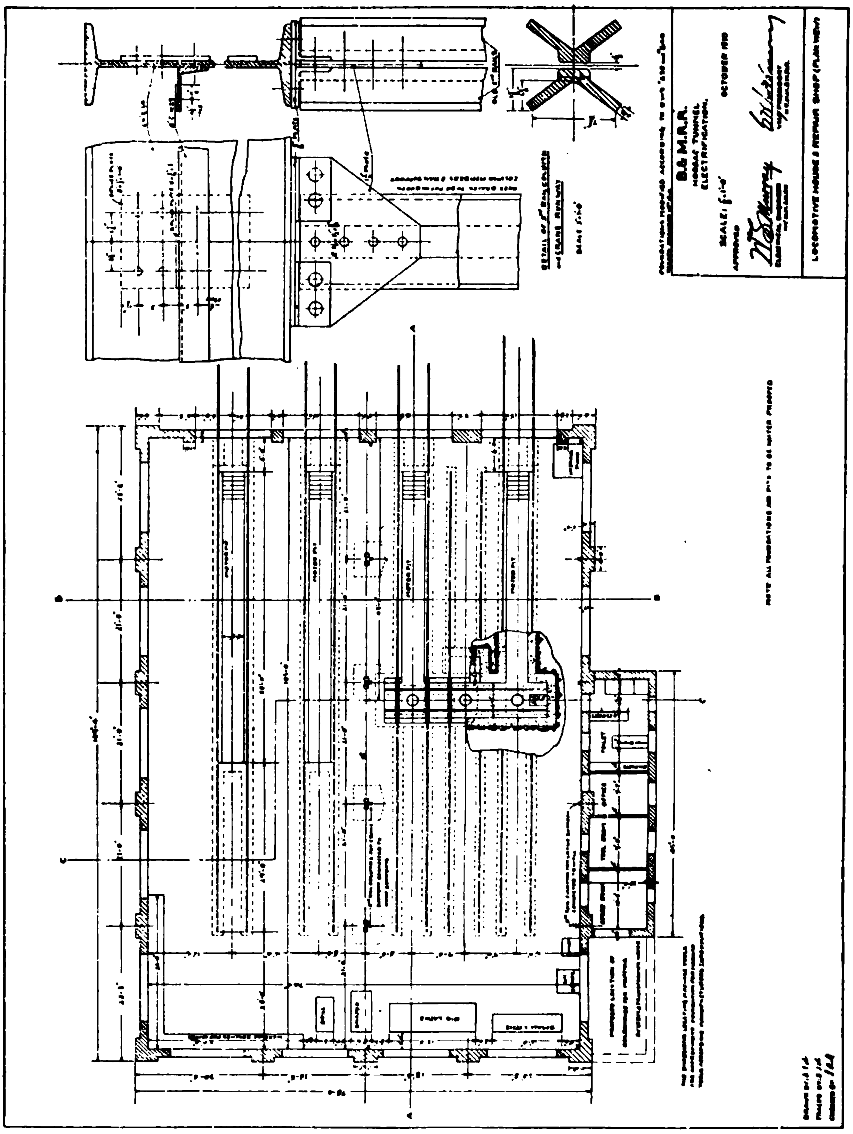


FIG. 74.—Hoosac Tunnel locomotive repair shops

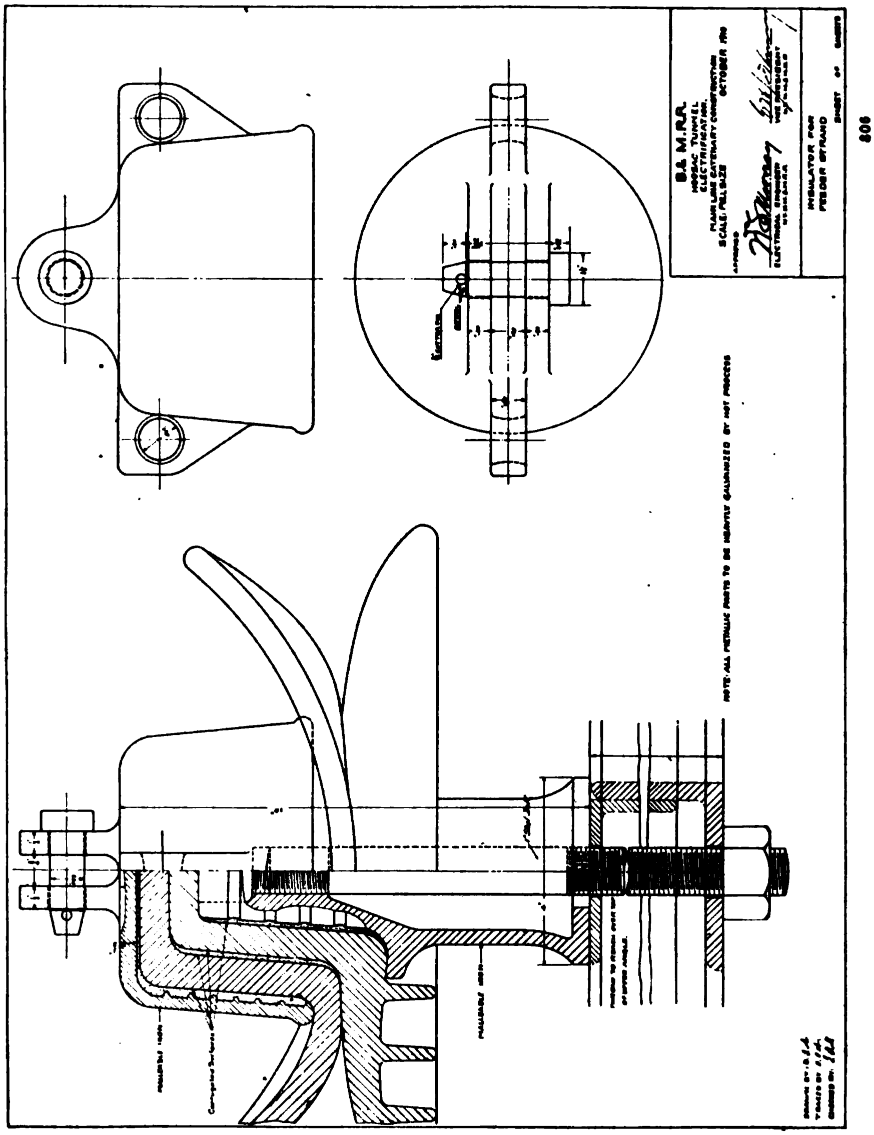


FIG. 75.—Insulator for feeder strand, Hoosac Tunnel

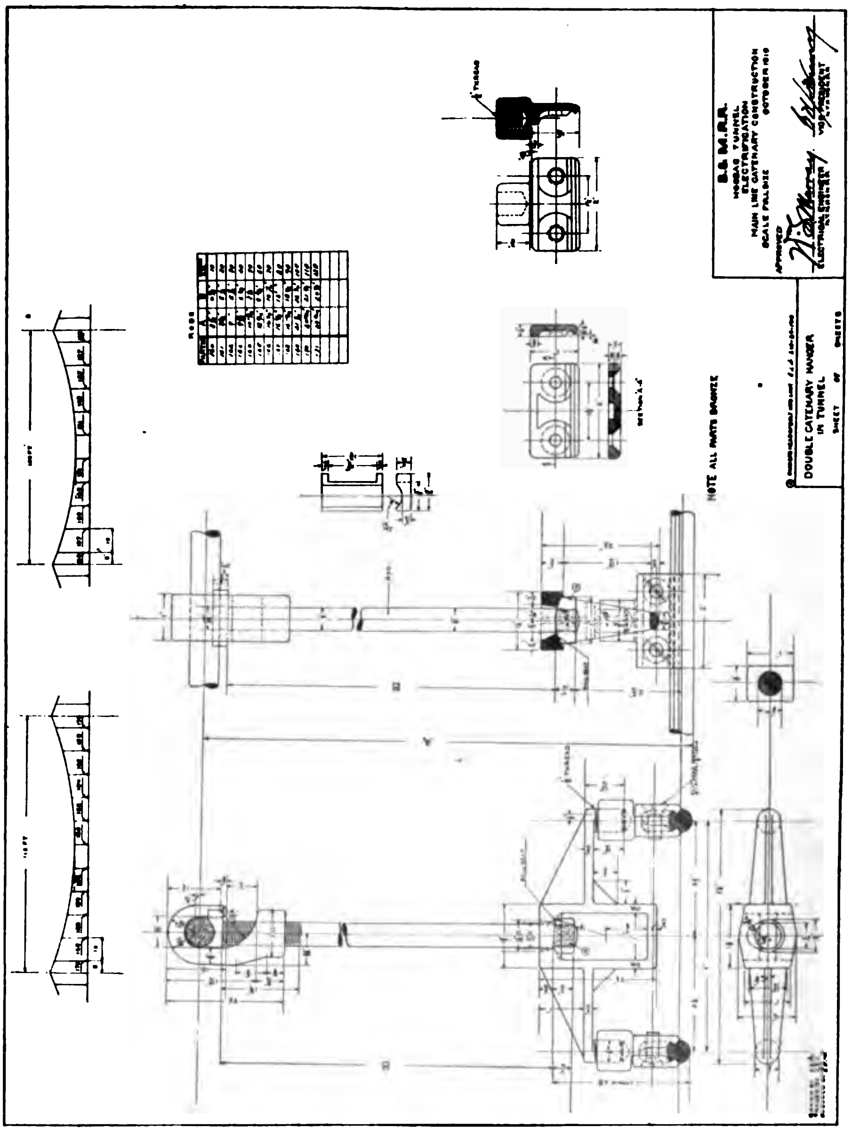


FIG. 76.—Hoosac Tunnel double hanger

DISCUSSION ON "INDUCTION MACHINES FOR HEAVY SINGLE-PHASE MOTOR SERVICE," "ELECTRICAL OPERATION OF THE WEST JERSEY & SEASHORE RAILROAD," "ANALYSIS OF ELECTRIFICATION." CHICAGO, ILL., JUNE 28, 1911.

Frank J. Sprague: I have a somewhat proprietary and professional interest in Chicago. It is true, as the President has said, that my inaugural address in 1892 was on the coming developments in electric railways. That was some nineteen years ago. It was the same year when Charles J. Van Depoele, that ingenious, persistent and hard working pioneer in the electric railway field, gave up his earthly activities, and left his name, his influence and the record of his early work, but also a continuing loss to a new development and to a great industry.

This morning I glanced over the address which I made at that time, and were I to write a paper at the present moment upon this particular subject I would in few particulars change the conclusions at which I then arrived. Those were early days in electric railroading, and possibly I may be permitted at this date to quote one or two of my remarks illustrating my then prophecy, if you please to call it so, and my general attitude. That was only three or four years after the beginning of the commercial development of the trolley system, when, on account of the active development of that field and the ambitious hopes of electrical engineers and manufacturers, the electric railways of this country, city, urban, suburban, interurban and trunk lines, were in a few years to be converted to electric lines, and the knell of the steam locomotive sounded. It seemed to me at that time necessary to indicate the possible order of development of electric railways, and to utter a word of warning against undue optimism. Speaking of trunk line operation, I said: " Turning now to the greater powers, we must not confuse the terms " large powered " and " trunk line " work. They are two statements which I think will need no corroboration. If we had a continuous train movement completely occupying a track system, there can be no question but that its operation from a central source by electricity would be more economical than if operated by steam locomotives. So, too, if a large number of units in reasonable proximity are moved, and the starting and stopping so regulated that the total demand on the central stations is fairly continuous and equal, then there is no question as to economy of electric propulsion as compared to steam. On the other hand, the operation of a single unit or very few units over a long distance would be so uneconomical and afford so small a return on the investment required as to make it prohibitory. Between these two lies the condition of operation where steam and electricity meet on planes of equality; as the number of trains decreases steam operation is more economical, as the number increases electricity must be preferred."

I further said: " It seems to me the growth of electric railways will proceed something in this order:—First, the street systems in the various towns, then connecting lines between adjacent towns, following the line of highways, then along connecting lines, either on the track of existing steam lines, or growing bolder, on exclusive rights of way. Then will come suburban traffic on a large scale, and freight transfer systems, and finally the more ambitious project of trunk line service under limiting conditions such as I will specify. It has been very properly said that a man will make his first long ride on electric railways by transferring from one town system to another, through connecting links, rather than on individual roads."

As it was my privilege at that early date to here record convictions which time has confirmed, there is another reason why I should have a kindly feeling for Chicago. Ten years after the inauguration of the pioneer Richmond trolley road a combination of circumstances led me to develop the multiple unit train control system, and I sought, at my own expense, to make a demonstration of that system on the then steam operated Manhattan Elevated railroad lines in New York, because the system promised radical advantages in economy of operation and increase in capacity. Despite many attempts, I was not able to make it there, and it was not until the South Side Elevated Railroad in this City, having passed through the hands of a receiver, found it necessary to change its motive power to electricity, that I found an opportunity to demonstrate the value of my invention of multiple unit control. It was due to Chicago engineers, Messrs. Sargeant and Lundy, who gave me their personal confidence, and to the courage of the capitalists back of the railroad, that in Chicago was made the first beginning of that which has become now so vital and essential to all electric railway operation on a large scale.

Now, Mr. President, I presume Mr. Wood's paper has been presented in its order?

The President: Yes, all three papers have been presented.

Frank J. Sprague: I do not feel confident to discuss Mr. Alexanderson's paper. He has made an interesting suggestion for the use of alternating current with a split-phase device, by means of which, with a single phase supply, he can make use of the polyphase motor. As experimental developments are in a very active state of progress, I think it is useless to prophecy what the possible results will be, but rather to wait and see what the outcome is.

In considering present problems, let us note for a moment what the conditions were at the time I made my inaugural address. All work was then practically being done with direct current, with limiting potentials of from 400 to 600 volts. The direct current motor was being rapidly developed, but single phase and polyphase motors were almost unknown. The static transformer was just coming into use, and the motor generator had been introduced but was not meeting with any widespread applications. The rotary converter had been invented but was almost an unknown piece of apparatus.

The limitations, however, of direct current at the pressures then common had become manifest. I had already, some three years earlier, advocated much higher direct current potentials, which have been since materialized; and in the early days of electric lighting, when one of the local manufacturing interests was embarking in the developing of alternating current apparatus, I believe I was the first independent engineer to recommend to another corporation the necessity of alternating current transmission to supplement its direct current operations.

It has been stated that history is repeating itself, and that electric railway equipment will, therefore, follow a certain definite alternating current development. Quite probably history will in many ways repeat itself, but if so it will be along lines which are not exclusive, for that is not its usual habit.

Somewhat necessarily, it seems to me, there has arisen a difference between electrical engineers as to railway systems which has given rise almost to the establishment of certain cults, and the zeal of the advocates of each partakes something of religious fervor. Now the problem we have to face is very much like many others in the use of electric power. It is to generate and transmit energy with the maximum of reliability, convenience and economy, and then to use it in motors variously applied; the one thing which differentiates the railway problem from all others is that the motors are on moving vehicles, and hence the grouping is variable, both in amounts and distances from the source of supply, while the total power is oftentimes small compared with the distance over which it is distributed.

Were any particular feature of the problem to be discussed there would probably be little difference among engineers as to the best solution. For example, all would agree that the central power plant should be situated where the cost of construction and the supply of fuel and water, labor and incidentals would insure the maximum of reliability and economy; that such a plant should be equipped with turbines direct coupled to three phase generators, wound for a comparatively moderate potential, and operated on closed circuits. Transmission would likewise be by polyphase currents at potentials determined by local conditions, to which end, and for the providing of the proper potential at the railroad, static transformers would be the necessary adjunct at both ends of the transmission line.

They would also probably agree that provision must be made for supplying the railroad in such a manner that it could be sectionalized, both as to divisions and tracks, so that the entire system would not be disorganized and thrown out of operation because of accident to any part.

They would agree also that there is a variety of service to provide for—freight, through passenger and local and suburban services; and that some trains should be pulled by single locomotives, others by double headers, yet others by locomotives both at the head and in the body of the train, and still others operated by motor cars grouped into trains on the multiple unit system.

Again, they would agree that current must be supplied to the trains along the right of way by working conductors in the form of an overhead trolley, variously erected and supported, available for single or polyphase currents at all practical potentials and for direct current at much higher potentials than have been common, or in the form of a third rail, protected or otherwise, available only for direct current.

Coming now to motors, it would also generally be agreed that the polyphase motor has the highest weight-efficiency, and that the direct current stands next in order, while the single phase has less output per unit of weight than either of its rivals; that the polyphase motor requires besides the track two conductors, and has the limitation of constant speed, while the other two types of motors require but one conductor beside the track, and have variable speed characteristics. Both of the alternating current motors ordinarily would require static transformers on the locomotives, while for direct current operation rotary transformers or motor-generators must be used at the substations.

Also, in the United States, there are three alternating current frequencies in extended use, namely, twenty-five, forty and sixty cycles, and where a single-phase motor is used frequencies from 25 down to 15 only are practically usable, the latter being more favorable.

Taking all these various factors into account, the problem must necessarily be a compromise in settlement; but despite this fact, and the further fact that the supply of power for railway operation is but a fraction of that used for all purposes, many would differentiate the railway supply from all others and set up a standard for universal acceptance.

It is unfortunate that in so doing there is a disposition in many quarters to base comparisons upon arbitrary limits of development on the one hand, and unquestioning acceptance of results accomplished or promised on the other, despite the fact that engineers, the world over, when brought face to face with specific problems oftentimes arrive at different conclusions. It seems to me that this is a wrong attitude, and that the duty of the electrical engineer is to encourage the fullest development by every known system, so that he may, with open mind and in the full light of actual experience, decide for the best whenever he has to consider any specific problem, even if when some other is presented his decision may be different.

In short, while there are many things that can be or are standardized there are some things which in my judgment can not now, and perhaps never will be made universally exclusive.

As Chairman of the Railway Committee, therefore, it has seemed to me that we should have arrived by this time to a discussion of Steam *vs.* Electric operation, based upon known operating facts and known construction costs, whatever the system used; and I repeat the time is inopportune and the occasion unwise that brings up at present any discussion which attempts a present settlement of the question of this or that predominant system. To this end, I have continually urged the getting from existing corporations actual facts, not promises or predictions, but facts concerning operation in that same detail that we have for the operation of urban or interurban railways.

We have been passing through an experimental stage of exceeding importance and far reaching consequence. The single-phase development promised much, it has disappointed much; it has been watched with a great deal of interest with a desire to know the results. It received its first impulse in this country on the interurban railways, and the history of that development has been interesting. All installations here have been put in through the instrumentality of two companies. I am not entirely certain of my statistics, but of the six or eight single-phase equipments put in with the apparatus of one of these companies, one only is now in operation. Some of these roads have gone into the hands of receivers, as it is true other roads under other systems have gone, and direct current has taken the place of alternating current operation. Notably, there is the case of the Baltimore, Washington and Annapolis road, probably one of the largest and most influential examples of interurban operation which we have in this country, and one of the most suggestive.

Now we have in operation a number of roads on a sufficient scale to get operative facts, let them be what they are. We have in New York three great terminal equipments. There is the New York Central and Harlem, operating at 650 volts on direct current supplied from an under-contact rail, and the New York, New Haven and Hartford, operating from Woodlawn to 42nd St. on direct current, and from Woodlawn north and east to Stamford by the single-phase, with an overhead trolley. Both of these have a considerable mileage of tracks. There is also the terminal operation of the Pennsylvania Railroad into New York City, which is on the direct current system, and the extensive Long Island Railroad development, which may be considered essentially a suburban system, also aggregating a very considerable mileage. Then there is the West Jersey and Seashore Railroad, running from Camden to Atlantic City, a distance of about eighty miles, with a trackage of one hundred and fifty miles, converted a few years ago from a steam line into a direct-current system.

Whether from fear of the Interstate Commerce Commission, or the demands of commuters, or because of certain unsettled conditions, or because possibly the circumstances are such that they do not care to have it impressed upon them that electrification might take place elsewhere under other conditions—railway officials have manifested a great reluctance to give the actual facts as to costs of operation, not predictions of what may be sometime, but what, under the existing exigencies of the service are the actual facts at the present time.

Of course, this operation is dependent on a number of factors, and the first is the cost of creating power, of which we have heard so much—in short, the operation of the power station. This is a factor which has become pretty well known in its characteristics, its cost, reliability and what not, on all ordinary electrical work, but which for some reason or other, has been kept with extraordinary secrecy from the ordinary knowledge of interested engineers where it applies to these larger trunk line installations. I do not intend to unduly criticise that attitude, although I think it is a mistaken one.

During the past year, therefore, I have bent my energies to find out if it were not possible by some means, through some channel, to bring out the facts, so far as they can be brought out, for comparison; because, after all, it is facts we want, not theory. Comparison of power house operation has for sometime, it is true, been privately made in great detail, and for mutual advantage, at the Port Morris, the Long Island and the Westville power houses. Later there has been added the Jersey City and Marion plants. Up to December, 1910, those were the only ones of these large railway power houses (I should have included the Interborough of Manhattan) which were making direct comparisons. I believe that in February last the New Haven consented to coöperate in making these private comparisons. But, really, why should not all, and freely, make public the facts?

Mr. Wood's paper was originally compiled for the purposes of presenting to the general manager of his division the facts contained therein. The Railway Committee of the Institute asked Mr. Wood if he would not request, as a courtesy and privilege, his general manager to allow the actual facts of the cost of operation of that railroad, as contained in the paper, to be presented at this meeting. Mr. Wood was fortunate enough to get the consent of his superior official to that publication. It has, I believe, set an example which other railroads must follow in time. Mr. Wood's action not only is highly creditable to his capacity and his persuasive powers, but the presentation of facts which he has made will prove in the end one of the most important, because of its initiation in getting at results, which has ever been laid before this Institute. I think that the thanks of the Railway Committee and the members in general are due to Mr. Wood for having been able to present these facts as he has, and to have done it with such perfect frankness.

I will not hold our electrical engineers entirely responsible for the lack of information. They are, after all, the servants of the railway officials, and railway officials, sometimes I think mistakenly, sometimes rightly, think perhaps the time is not ripe, the extent of operation not sufficient to justify them in making public the actual facts of the operation. But it seems to me, after all, we as engineers can differentiate the various factors that go to make up these reports; and when a railway official gets that opinion into his head then we may be trusted with some degree of confidence in dealing with the facts when laid before us.

Mr. Wood's paper has some features to which I wish to call particular attention. The time of installation occupied only seven months, a most creditable performance. The power-house report for 1910 makes the cost per kw-hr. .542 cents, a creditable result under the circumstances. In passing, it is of interest to note that at the Jersey City and Marion power stations, although there is a difference in year 1910 of nearly one hundred per cent in the basic cost of coal, there is a difference of only eight per cent in the cost per kw-hr., and the actual cost is less with the station which used the higher priced coal, but not for that reason. The transmission efficiencies from power house bus-bar to substation bus-bar on the Westville line increased from 72 per cent in 1907 to nearly 82 per cent in 1910. That makes the power cost at present 0.542 cents per kw-hr. at the central station and 0.646 cents at the substation; and the cost of operating the substations based on this output is 0.108 cents per kw-hr.

The total cost of operation per car mile in 1910 averaged something over 18 cents, varying from a little over 12 cents to nearly 25 cents per car mile, a variation which is affected by frequency of service, density of movement, and the use of current for lighting, heating and various other purposes. While there was this variation of nearly 13 cents in cost per car mile, the cost of power delivered varied less than 3 cents. Out of the 18 or 19 cents average total cost per car mile of operation, of which only 3½ cents represented the cost of power, the cost of the sub-station attendance, maintenance and upkeep was three per cent of the total. The upkeep of the high tension transmission line was something over $4.00 and the third rail $6.50 per mile, while the upkeep of the trolley was six times that of the third rail per mile.

Coming now to Mr. Murray's paper, it is somewhat difficult for me to treat it with the thoroughness which its voluminous character and its wide dissemination would ordinarily be expected to require. What was hoped for, and is needed more than all else, is that presentation of actual construction and operating costs so vital to any intelligent consideration of the subject of steam railroad electrification by any means whatever—not a special plea for a particular system, no matter how ardent its advocate may feel in its behalf.

I doubt not that among the many engineers of occasional conservative tendencies—the natural result of some years' experience in spending one's own and one's client's money in industrial development, and sometimes seeking an acceptable excuse for a dearth of dividends in times of increased cost of living—I am included (to borrow Mr. Murray's description) among those "who claim some recognition in the field of railroad engineering," and who believe that the time has not yet come, if indeed it will ever come, when the electrical engineer, in his broader responsibility, can say that there is but one system of electrification adequate to meet all the varied problems of railroading.

Certainly such cannot be said, with any degree of lasting authority, at the present moment; one might as well say that we have reached the limit of the tireless activities of the myriads of workers in the electrical fields, and that the curtain has fallen on new discoveries and inventions. Equally mistaken would be the claim that all railroads are ready to be electrified, or on the other hand that none are, or that a hard and fast line of demarcation can be drawn between those which should and those which should not consider a change of motive power.

The author has presented many interesting isolated facts, some of undoubted value, and varied such presentations with a plentitude of drawings from the all-embracing and constantly accumulating records of the New Haven engineering department. But one looks in vain for some correlated and definite facts as to the costs of construction and costs of operation, either individual or comparative. Even the simplest facts as to cost of overhead installation, of locomotives and motor cars, or costs of power production and distribution, or of locomotive and motor car repairs and upkeep are not given.

I will take only a few moments to touch on one or two points in Mr. Murray's paper. There is here presented, what? Not the single-phase system, as ordinarily understood, but what I may call the author's system. I think it can be all found in his two earlier papers. What are the characteristics of the system? Single-phase transmissions at a potential limited by the requirements of the trolley wire, from central stations equipped with generators built with variable voltages and operated with grounded circuits; the abolition of step-up and step-down transformers, thus giving up the absolute and necessary freedom of determining economically the potential of long distance transmission from a central station; a potential of 11,000 volts or higher on a trolley line in contiguous territories, but with entire freedom to change that potential to something different on remote lines; the abolition of the single-phase, 25-cycle motor, and the substitution therefor, as a possibility in the near or the dim future, of a single-phase induction motor, or in lieu of that the much criticized direct current motor supplied by a mercury rectifier or its equivalent. Furthermore, we have 25 cycles as the preferred frequency. In this last, Mr. Murray is somewhat at variance with the practical experience and recommendations of some others. We find the German, Swiss, Italian and Swedish engineers, and one of the great manufacturers of this country, who supplied the apparatus for the New Haven road, recommending, where alternating current is to be used, about fifteen cycles as the proper standard for trunk line operation, while many of our prominent engineers in this country, men of wide experience and ability, and prominent in this Institute, endorse 25 cycles. We find eminent engineers abroad recommending polyphase apparatus entirely, others prefer single-phase, and here we have some who believe in developing the direct current to its logical limits so that what it can accomplish may be safely and fairly measured in comparison.

Mr. Murray says, " We have made the system work, now let us make it pay." After you have made a system reliable, and within its possible economy workable, the way to make it pay is to get traffic, and also to extend the use of the system to an engine division. Mr. McHenry, Vice-President of the New Haven road, is quoted as saying that, after all, if the passenger service can be operated by electricity, every wheel on a division ought to be turned by electricity; and he points out the important fact that the schedules of the freight operation can be so arranged as not to materially add to the burden of maximum demand on the central and substations. It seems to me that this latter day suggestion to operate every wheel of a division by electricity is very familiar. When the New Haven system was put in I said that if there is any reason for the adoption of this system on the New Haven road, even within the limits of the electric zone, the operation should be extended to every wheel, that passenger trains, multiple unit and through, and freight trains should be operated electrically; in short, one should be able to get the diversity factor on a railroad as well as elsewhere.

But I am going one step further. I am one of those who have a sort of growing belief that that diversity factor should be extended, and those who went yesterday afternoon to the magnificent Commonwealth Edison Company stations, and saw single generators of a continuous capacity two or three times the average power consumed the year round on the West Jersey line, and know something about the diversity of service on these plants, must realize, it seems to me, that the day of individualizing the railroad as we are in the habit of doing will pass, and that its demand for power, with increasing reliability of central station operation, will be met by great central stations connected up together, and further, that these central stations will be engaged not only in supplying electricity to railroads, but for every purpose for which electricity can be used within the radius of their operation. The New York Central and the New Haven roads could be supplied today, and supplied with less money, without one dollar of investment in central stations, by a general station of the capacity, size and system of operation of that of the Commonwealth Edison Company.

This statement has a bearing directly on the situation in Chicago at the present time. Here are more than a score of railroads entering the City, and an attempt to issue a mandatory decree by the Council that there must be electrification of these lines within the city limits within a certain time. I am opposed to mandatory legislation of that kind, but when electrification does come it will be for the engineers in charge to determine it. Then they should keep one problem in mind: How can the maximum benefit be obtained with the minimum of burden to the railroad and the community? That will mean a consolidation of power plants, so that the current will be supplied from a limited number of well situated distributing centers which will provide not only power for the railroads, but for everything else within the radius of their action. I think that this means polyphase transmission, and quite likely direct current distribution.

We have had one or two criticisms of the storage battery. Most people do not know why the battery was put in on the New York Central railroad, of whose Committee on Electrification I was a member. It was installed on the advice of every member of the Commission, because of the then absolute necessity for the fullest measure of insurance, not because we expected to lower the kw. cost much. We cut out part of our generating equipment, and spent $1,000,000 for batteries, and increased the then reliability of the plant from a practical point of operation by a large margin. There have been times when that insurance was worth a good deal of money. There are in New York and Chicago two of the greatest central power stations for general supply in this country. I believe there are not less than 40 to 45 batteries in the New York City plant, and a correspondingly large capacity in storage batteries in the Chicago plant; and if you ask the managers of these stations what is the use of the battery, they will tell you that it is not for the economical production of power, but for the insurance which the battery affords. I do not know to what extent storage batteries may be used on railroads in the future. The increase in the general reliability of central stations and in the limits of rotary converters are such that sometime we will not need a battery, but if a battery is to be used, remember that it is for insurance; do not go on the mistaken idea that it is put in to materially lower the cost of power, all things considered. When it is used it is applicable to direct current distribution, and not to single-phase distribution except by the introduction of moving apparatus of the full required substation capacity.

The time is so limited that some notes I have made I shall pass by for the present, but I wish to impress on you all my conviction, and I believe I have some right to express a conviction in a matter to which I have given twenty-five years, that the battle should be between steam and electricity and not between systems. I say, " God speed " to advance by whatever system, be it single-phase, polyphase or direct current, but when the merits of systems are discussed, I for one will always stand absolutely opposed to fatuous comparisons which accept all the promises of the one and deny the possibilities of the others.

Edwin B. Katte: I have not had an opportunity to read Mr. Wood's paper with the care that is necessary to discuss such a paper in detail. The real value of his paper is as an incentive to draw out similar operating information, and I will be glad to coöperate with the Railroad Committee in an endeavor to obtain more such data. I was sorry to note on the very first page that there would be no comparison with the cost of steam operation. We do not yet know the relative cost of steam and electric operation on trunk line railroads.

Among the very interesting points which attracted my attention was the comparison of the third-rail and the trolley systems. Mr. Sprague has already called attention to the fact that the trolley per mile costs six times as much to maintain as the third-rail. Again, in Table 8, we find that the detentions due to all third-rail troubles were twenty-eight minutes, and to the trolley troubles they were one thousand nine hundred and twenty minutes. At another point the first cost is given, and it is interesting to note that the cost of the overhead trolley is almost exactly the same as the cost of the third rail.

L. C. Fritch: I do not expect to talk to you this morning from the standpoint of an electrical engineer, but rather from the standpoint of the steam railroad engineer. I am very glad now, as a member of this Railroad Committee, that I did not prepare a paper for discussion at this meeting, seeing how Mr. Murray's paper is being criticized, but I will say that I did prepare a paper on the subject of the electrification of steam railroads as applied to terminals, but it was so proelectric, that when the railroad men received it it was suppressed. One President of a railroad said—" You are too enthusiastic on this subject, you have too much electricity in your system, and your views are too advanced. But from the investigation I have made so far I have reached this conclusion—" that there is work in transportation in heavy trunk line service that the steam locomotive cannot perform, but there is no work in transportation on heavy trunk line service that an electric locomotive cannot perform more efficiently than the steam locomotives. While I am not as narrow minded, I think, as some railroad men, I am certain it is possible to demonstrate that phase of the question when considering the application of electricity to heavy trunk line service. It seems to me that railroad men are making a mistake in endeavoring to ward off something that is inevitable. The recent development of the Mallet type of locomotive, in my opinion, is the dying gasp of the steam railroad men to maintain steam as a motive power on railroads. When we consider the Mallet type engine, weighing 615,000 lb., total weight, the weight on drivers 550,000 lb., with a tractive effort of 137,500 lb., and a ratio of pounds on drivers and tractive effort of 4, and then take the Pennsylvania railroad type electric locomotive of the passenger type, total weight of 332,000 lb., weight on drivers 207,000 lb., and tractive effort of 69,300 lb., and then take into consideration the overload capacity and the ratio of driver weight to tractive effort per pound, of 3, I think the argument is in favor of the electric locomotive. The railroads in this country have spent millions of dollars in grade reduction, line revision, and tunnel excavation, which, if it had been spent for electrification of these lines, in my opinion, in many cases it would have shown more economical results.

Now, as to the question in Chicago, the situation here is peculiar to itself and I am not altogether agreed with some of the statements made here this morning, that it is not a question of the systems, it is a question as between steam and electricity. It is true, it should be a battle between steam and electricity, but the question of the system must be established. As long as the system is not established, you are simply furnishing ammunition for those who do not desire to electrify.

The situation here in Chicago is this: We have some twenty-five trunk lines in Chicago. There is an interchange of freight traffic between all of them; the locomotives of one company go into the yards of every other company. Now, if one company should adopt one system, and another company adopt another system, it is readily seen how impossible the operation would be. I am an advocate of a universal system, or a system of systems that will be mutually interchangeable, and unless you make progress along that line, electrification is not going to make much advance in heavy trunk line service. In New York, of course, the situation is different from what it is here, but there is no reason why this question cannot be solved, and I think that instead of electrical engineers having a battle of systems, they ought to get together and devise a system or systems that will be mutually interchangeable.

Considering further the Chicago situation, which I think will be of interest to you, it has always appeared to me that the question has been approached from the wrong angle. It has always been a question of—Will it pay? While, of course, the financial question is the all-important question, yet there are instances in this city where electrification on certain branches of service will be justified, not as a whole perhaps, but an initial installation will pay, and that will demonstrate whether an extension of electrification will be justified. That, in my opinion, is the proper way to investigate the question here. There has recently been a Commission appointed to investigate the question in Chicago, and I do not think it will be difficult to write that Committee's report now, because statements have been made that it will cost $250,000,000 to electrify the railroads in Chicago. I do not agree with that statement. I think a sum half that amount would meet all the objectionable features of steam operation in Chicago today. The situation here demands not only electrification, an investigation into the matter of electrification, but a revision of the entire terminal situation. The railroad tracks in Chicago were laid principally as though shot out of a gun, without much system or relation to each other. What should be done, in my opinion, is that the railroads, as a whole, should get together and revise their terminals, and in my opinion, they should electrify them within certain reasonable limits; that common entrances should be provided and a group of passenger stations, with a joint entrance which could be electrified. If the freight terminals were made joint freight terminals, and all interchange traffic that has no business within the Chicago business district kept out of it, the local business could be handled in a much more simple manner than it is handled today and lend itself more readily to electrification.

There is one point that Mr. Murray has brought out, which I consider very valuable at this time, and that is the question of the electrification of switching terminals. In my opinion, that is one of the most important matters that has been brought out in these papers. He has shown that there is a possibility of a saving of at least thirty per cent in the number of units of switching locomotives. Now, take one railroad in Chicago having forty-five switch engines, a reduction of 30 per cent, would mean fifteen locomotives, and taking these locomotives at an average cost of $10,000 a year per locomotive, that would mean $150,000, which capitalized would mean $3,000,000. That will go a long ways toward electrifying a switching terminal. These are matters which we should bring out and develop, and wherever you raise the question of electrification, in railroad circles, you will be met with the statement that never yet has a large freight terminal been electrified, that it is not possible, and is impracticable in every sense. I do not believe that. I believe that in yard operation it is possible with overhead construction, using either direct current or alternating current, such as Mr. Murray figured out, and that it can be built for from $1500 to $2000 for single track per mile. It is not a question of the number of tracks. If you have a yard with fifty tracks, you can span these tracks, and that will remove all the objections to the third-rail or surface conductor which, of course, would be almost inadmissable in some instances. It would be possible to use a lower voltage in the yard that out on the main lines, where trolleys would be perfectly practicable.

J. L. Woodbridge: Mr. Murray in his paper states that storage batteries for trunk line electrification are not economical. He admits that a battery will permit more economical generation of power, but states that this increase in economy is offset by the increased output required (presumably to supply battery losses) and the cost of battery maintenance; and concludes his observations on this subject with the remark " It is of interest to note the passing of the storage battery theory; at least in as far as its application to trunk line conditions is concerned."

I desire to take issue with Mr. Murray on this point. So sweeping a statement would seem to call for a presentation of the facts and arguments upon which it is based. As it stands, it appears to be merely the expression of his own unsupported personal opinion. Without knowing the source from which it was derived, a comprehensive reply is impossible; but I would like to offer a few remarks on the other side of the question, and present a few actual facts in support of my position.

Inasmuch as Mr. Murray is evidently looking at the commercial, rather than the technical side of the question, I shall confine my remarks to that aspect of the matter. The question is, therefore, can a storage battery be so applied to trunk line electrification and so operated that the increase of economy in the generation (and possibly the transmission) of electrical energy will more than offset the cost of battery losses, battery maintenance and interest on increased investment, if any. I believe that in many, if not most, cases of trunk line electrification a complete analysis of the problem would show that a storage battery, properly adapted to meet the conditions and controlled to produce maximum economy, will be a profitable investment. In support of this position I would submit a few actual facts.

About three years ago, the Chicago City Railway Company entered into a contract with the Commonwealth Edison Company for the purpose of power. The details of this contract have been published, and are well known. It provides for the payment of a unit price per kw-hr. plus a service charge of $15 per kw. per year for the maximum peak, this peak being the average of the maximum one hour peaks of any three consecutive days. In order to reduce this service charge, the Railway Company, who already had one battery in service at 77th Street, installed another much larger battery at their Plymouth substation. As a result of the operation of these two installations, the saving in the power bills after deducting maintenance, operating expenses, rent, insurance, taxes, etc., is sufficient to pay 12 per cent on the investment. Now it will, of course, be contended that this result is due to the peculiar terms of the power contract, which penalizes the purchaser for peak loads to such an extent that the battery installation becomes a commercial proposition. This is very true, but if this power contract is fair and equitable to both parties in all its terms and conditions (and of this there can be no doubt in view of the standing and ability of the men who drew it up), if the terms of sale are logically based upon the conditions of power production, and the prices are truly proportionate to costs, then the battery investment would be equally profitable if the Chicago City Railway Company were developing its own power. In fact, it should be more so, since the terms of the power contract undoubtedly make it necessary for the Railway Company to discharge its batteries on peak loads on some occasions when there would be no economic advantage in doing this. If the Chicago City Railway Company were developing its own power it would be possible to reduce the amount of work which the battery is now called upon to do, and thus reduce the cost of maintenance.

The Chicago City Railway is not, of course, a case of trunk line electrification, but it will doubtless be conceded that trunk line service is still more favorable to the storage battery, in view of the smaller number and heavier demand of the train units, and the more irregular and intermittent character of the load.

The economy arising from the presence of a storage battery in connection with an electric system may be effected in two different ways.

First, a careful analysis of the cost of producing power under the various load conditions will show that not every kw-hr. is produced at the same cost, but that this cost varies widely at different times of the day, and under different conditions of operation. In general, the power produced below the average load line at a steady rate, for many consecutive hours, is developed at minimum cost, while the power produced for the short peaks above the average line, is produced at maximum cost. The difference between these two costs of power is actually much greater than many engineers are apt to realize. To develop energy at the minimum cost, and store it in a battery, to be again delivered to the system under conditions when the cost of developing the power directly would be a maximum is one method of deriving economical results from the operation of the battery.

The second way in which a storage battery can effect improved economy of operation is by its mere presence on the system as a reservoir of energy ready to deliver its output at a moment's warning under any unforeseen conditions of demand or power supply. The mere fact that such a reservoir is at hand, even though it be seldom called upon, will permit a more economical operation of boiler and engine room than would be possible if some other form of generating apparatus, such as boilers, engines and generators, must be kept in readiness for emergency service. The batteries installed in connection with the New York Central electrification are handled in this way.

A review of recent progress in storage battery engineering, and recent development in automatic controlling apparatus, will reveal a tendency to limit more carefully the operation of batteries to the particular class of work for which they are especially adapted, and to eliminate a large amount of battery work which does not make for economy. It is not economical for a storage battery to take *all* the peaks above and below a given average load line. Much of this class of work, which has heretofore been thrown on storage batteries where they have been installed, would be more economically handled by the generating apparatus. This fact is being more and more clearly recognized, and automatic controlling apparatus has been developed to discriminate between the different classes of fluctuations in such a way that only those peaks and fluctuations which can be economically carried by the battery, are referred to it. This means that the size of the battery may in some cases be reduced, the first cost decreased and the maintenance charge lessened. In any case the efficiency of operation is improved.

The use of storage batteries for stand-by service has also assumed greater prominence in recent years, and while this use is largely found in electric lighting systems, it is occasionally applied to railway work. The operation of the battery in connection with the Baltimore Tunnel electrification is in some ways an example of this class of service. The Baltimore and Ohio Railroad Co. has recently entered into a contract for the purchase of power from the Consolidated Gas, Electric Light and Power Company, under the terms of which the cost of power is increased by peaks and fluctuations above certain specified limits. The battery is operated to prevent the power demand from exceeding these limits. Under ordinary load conditions the battery is merely floating on the line, and is prevented from charging or discharging when such work would not have any effect in reducing the cost of power. When, however, the demand exceeds the limit set, the battery discharges, taking all load fluctuations above this limit. This operation, which may be called stand-by regulating service, is produced automatically by controlling apparatus recently installed. The result is that the battery is called upon to do only such work as is commercially economical. This is another instance in which the terms of the power contract between the user and the producer of power make the operation of a storage battery commercially economical. The terms of this contract are the result of a careful analysis of all the conditions of power production and utilization, this analysis being equally applicable if the operating company were producing its own power.

It may be interesting to note that in neither of the cases cited above is it a part of the battery's function to regulate the momentary fluctuations of load for the improvement of the lighting service of the company which is producing the power. The momentary fluctuations in both cases are ordinarily allowed to fall on the power company's system. Refinement of voltage regulation, which in some situations is the motive for the installation of a battery, is not called for in these two examples and the argument for the use of storage batteries in these cases rests on commercial economy only.

Dugald C. Jackson: The electrification project of the New York, New Haven & Hartford Railroad, for handling trains entering and leaving New York, has been a center of interest to all engineers having electric railroad relations; and the courage and vigor with which the engineering staff of that road attacked the problem of designing, constructing and adapting a then substantially untried alternating current system to meet the needs of an active steam railroad traffic has been a matter of satisfaction and congratulation to all. The accomplishment that has been reached in four or five years is remarkable, and is a monument to the fidelity and skill of the engineering staff which carried it out.

The drawings which accompany Mr. Murray's paper give concrete evidence of some of the work done and some of the difficulties which had to be overcome to make the working of the system a success. I speak of difficulties—they obviously were tremendous, and when faced in the course of work must at times have seemed nearly insuperable. Their spikes and claws appear relatively few and harmless when viewed in the retrospect afforded by this paper, but the credit to the engineers whose courage, foresight and ability wrought this result, should not be diminished. When we admire the courage evidenced by the New Haven Railroad organization, by the adoption and installation in service of its Stamford-Woodlawn system of electrification, and their skill in overcoming the appalling difficulties which faced them, we must also acknowledge that the adoption of 11,000-volt trolley construction in the wet and difficult conditions of the Hoosac Tunnel proves that their courage remains unbroken.

There is no longer any question of the physical ability of electric motive power to cope successfully with all of the problems of trunk line, suburban or terminal service, and with a reliability excelling the service by steam motive power. The only possible exception may be that of the railroad yard, but any one who goes to Mr. Murray's little yard—little to be sure, but effective—over which he now has wires, cannot but be impressed with the simplicity of the situation there. I have not yet had an opportunity to look at Mr. Murray's switching locomotive, but from what he tells me it must be remarkable for activity and perfection in operation. Not only that, but we now have the proof that electric motive power is satisfactory for the work of moving trains in trunk line service, (as we have heretofore had proof of its adaptability in suburban and terminal service), and this with a reliability obtained which perhaps excels and, at least fully equals the records of steam motive power. These proofs have been made in a few years. Having made these proofs in relatively few years, we are bound to see yet better results as more experience is obtained. Well built electric machines are acknowledged to be among the most reliable machines made by man, and the substitution of electric for steam motive power removes the least reliable part of the motive power of the railroads, that is, the engine and boiler, from the road, and establishes them in larger and better perfected units located in stationary power stations where they can be properly inspected, supervised and cared for.

The physical success of electric motive power has been abundantly proved in trunk line, suburban and terminal service, for single-phase, polyphase, and direct current installations, in this country and Europe. It is undeniable that several Swiss roads have made a success of electrification, but perhaps they are too small to be compared with some of the great trunk lines in this country, and I will not go into a discussion of them. The Valtellina road was one of the earliest steam railroads to convert to electric service, and its electric service has been successfully maintained for years. Various other Italian roads give evidence of success. The London-Brighton installation in England has sufficiently proved its justification. Neither is physical success deniable in the installations at the Cascade Tunnel of the Great Northern Railroad, the St. Clair Tunnel of the Grand Trunk Railroad, the relatively new Detroit Tunnel of the Michigan Central Railroad, the West Jersey and Seashore Line of the Pennsylvania Railroad which Mr. Wood described, the lines of the Long Island Railroad, the New York Terminal of the New York Central Railroad, which Mr. Katte discussed, the Stamford-Woodlawn zone of the New York, New Haven & Hartford railroad, which Mr. Murray described, and the relatively new New York Terminal of the Pennsylvania Railroad, and other important installations in the United States.

It is being urged in some quarters that electrification of additional lines or terminals on a large scale ought not to be pressed forward, on the ground that engineering in this branch lacks standards. The data contained in the papers presented this morning, it seems to me, prove the substantial baselessness of that assertion, notwithstanding the fact that one dealt with an alternating current installation and one dealt with a direct current installation. The baselessness of that assertion is equally proved by the standards of electrical construction and apparatus of the New York, New Haven & Hartford Railroad, the New York Central & Hudson River Railroad, and the Pennsylvania Railroad. The fact that electrification may be made by means of either single-phase, polyphase, or direct current does not signify lack of standards, but is a patent of the ability of electric power to meet every requirement when the system adapted for particular service is selected and installed with engineering skill. In a situation such as exists here in Chicago, it would as Mr. Fritch suggests be criminal for the important roads to adopt systems which are not freely interchangeable. Some minor road may have a different system on account of not coming into the main systems, but the equipment of all important roads entering a place like Chicago must be completely interchangeable. This however may be accomplished, and involves harmony in engineering plans to bring it about. The prime point is, that electrification allows a choice of motive power which will most effectually serve the purposes of the particular terminal conditions.

It would be palpably absurd to assert that no standards exist in steam locomotive practice because Atlantic type, Pacific type, Mallet articulated and other types of locomotives are in common service in different parts of the country, where different conditions are to be met. I presume, in fact, that electric motive power has come nearer uniformity in standards, young as electric service is, than practice with steam motive power has yet attained. The flexibility of electrical equipment is illustrated by the capability of the New Haven motors and controlling devices to operate successfully and alternatively over the New Haven's own lines with its 11,000 volt alternating current delivered to the contact shoe by trolley wire, and over the New York Central's lines with its 700-volt direct current delivered to the contact shoe by third-rail. An argument against electrification on the ground that standards and conditions of interchangeability are not being or cannot be provided where they are needed is obviously untenable.

The only open question about electrification, *i.e.*, whether the improved service which is inherent with it can be established and provided without enhancing the present cost of service, is not answered in Mr. Murray's paper, or wholly in Mr. Wood's paper; and rumors regarding the fiscal achievements of the important electrification projects operating in various parts of the world are not sufficient bases to afford conclusions. It is obvious that steam operated trunk lines of light traffic and unimportant terminals are not at the present time reasonable candidates for electrification, and the open question, therefore, relates to important terminal centers and to trunk lines and suburban lines with reasonably dense traffic. A number of good clues to the answer to this question are already available from papers which have been read before this Institute. Good clues are further available in the continued satisfaction given by the electric operation of certain of the Italian, Swiss, and French railways (some of them doing both freight and passenger business), besides the two or three in England, the reports that have as yet been made public regarding the fiscal success of the West Jersey & Seashore and Long Island Railroad electrifications, the St. Clair Tunnel installation, and perhaps others, in addition to the very persuasive example put forward by the New York, New Haven & Hartford railroad in planning extensions of their existing electrification, with which they have had several years experience and with which they appear well satisfied.

It is to be further observed that fiscal comparisons between the New Haven electrification and its well systematized steam locomotive service probably cannot yet be flatly made. The electrification has only recently emerged triumphant from the pains of a developing system to a point where Mr. Murray is prepared to say that it operates under commercial conditions. Somewhat the same is true of the New York Central & Hudson River Railroad installation. Indeed, both of these installations are operated under the expensive conditions imposed by reconstruction work going on at the New York terminal, which must temporarily add cost to the handling of trains. Under all these obstacles, electrification seems to have "made good."

N. W. Storer: There are a few points which stand out in Mr. Wood's paper that I should like to refer to briefly:

First. The excellent showing made in the extremely small number of detentions due to the motive power, as compared with those due to other causes. The fact that the detentions due to motive power and weather conditions together amount to only 8.38 per cent of the total number, shows a reliability of the service, which would be increased but little if all of the delays due to motive power were wiped out completely. It shows that until the delays due to general traffic conditions can be substantially reduced, it is useless to go to an enormous expense to reduce the already almost negligible delays, due to motive power.

Second. The data showing gradual decrease in the cost of power, indicating what can be done by scientific management, is certainly most encouraging. I discussed this matter with Mr. Wood, who stated that he had had some of his own men take charge of the power house and substations operation, with an immediate reduction in the cost of operation as the result. The rotary converters in the substation were operating practically all of the time in the earlier days of operation, and much of the time unnecessarily. They found it entirely possible to shut them down a good part of the time, and in this way reduced the light load losses, thus making a surprising difference in the power consumption.

Third. There are some points in connection with the operation of trains also tending to increase the power consumption which should be noted, one of which is the number of brake shoes that are worn out. In the year 1910 we note that there were 6300 brake shoes changed. It would be interesting to learn how many kw-hrs. were required to wear them out. One cannot help calling attention to the advantage in introducing the coasting time clock or some similar meter system, which will tend to increase the amount of coasting time, and therefore to reduce the speed at which the brakes are applied, and finally decrease the wear on the brake shoes and the power consumption. If brakes are applied when the cars are running at a speed of 50 miles per hour they must absorb practically four times as much energy as they would at 25 miles per hour, and it is probable that four times as much brake shoe will be worn off. A reduction in the speed at which the brakes are applied in ordinary operation will therefore effect a great reduction in the number of brake shoes, as well as in the amount of power consumed.

In discussing this paper, I think some of the speakers have gone out of their way to make unfavorable comparisons between the costs of maintenance of trolley and third rail. The advocates of any overhead trolley system might well be alarmed if the costs of maintenance given in this paper were characteristic of all the overhead trolleys, but fortunately such is not the case.

The idea that we gather from the paper is that multiple unit trains with wheel trolleys, operating under certain conditions, at high speed, over a rigid cross-span construction, are very destructive to the overhead system. Anyone who is at all familiar with the cost of maintenance of the overhead trolley system of an ordinary interurban line would know at once that the cost of $440 per mile, as given in this paper, is extremely abnormal. Wheel trolleys are made at the present time that will operate safely at high speeds on a good overhead construction. The roller pantagraph, as well as the sliding pantagraph, will also operate well. The roller is now used quite extensively on the Pacific Coast, and with success. The use of such a trolley would unquestionably practically wipe out the cost of maintenance of the overhead trolley wire, as well as some of the numerous delays noted. The cost of the maintenance of the third rail is very reasonable—in fact, is lower than most third rail systems, because it is of the simplest form used. It is a good, substantial third-rail construction, but it is not protected, and this fact decreases the cost of maintenance.

I am very sorry Mr. Katte did not give us the cost of maintenance of the New York Central third rail system. This is practically the best protected system at present in use, and some information in regard to the cost of maintenance would be very illuminating. I do not recall that any figures have ever been published in regard to this, and I am sure that such information would be very valuable to many members of the Institute.

After reading Mr. Murray's paper, I am more than ever impressed with the thought that if the events of the last two years have shown anything, they have shown the unwisdom of making such dire prophecies as were freely made at the time the single-phase system was installed on the New York, New Haven & Hartford Railroad. It seems to me that any system which has so many advantages and possibilities as the single-phase system should have the united efforts of all engineers concerned in developing them at the earliest possible moment.

Now in regard to this question of standardization. I believe that both Mr. Murray and Mr. Fritch are right—we must have some degree of standardization before the great work of electrifying railways goes much further, and this can only be accomplished by getting together. I do not mean to say by this that we must immediately unite on the single-phase system for all future work, but I mean that an effort must be made to get the most out of each system that is proposed. I wish it understood in this connection that I am not prejudiced in favor of the single-phase system. I am personally engaged in the development of designs and the manufacture of apparatus for operating on all of the different railway systems, and in that way am making every effort to make the best out of each one of them. I have advocated in the past, and am still advocating, the single-phase system for use in certain places, but have never ceased to believe that the apparatus designed for the 600-volt direct current system is the standard for reliability. Having had a wide experience with all systems, I feel that I can give an unbiased opinion. All I wish is to see the best system adopted. We must have a certain amount of standardization, especially for cities like Chicago, where the motive power must necessarily be interchangeable on all of the roads, and we engineers should get together very soon and get something settled.

I want to emphasize the point Mr. Murray has made in regard to the advantage of the electric locomotive for switching service—a service in which it has been used comparatively little. It is ideal for that class of work, and certainly will be used a great deal in the near future.

FIG. 1

At the time the passenger locomotives now in use on the New Haven Railway were built, both the railway company and the manufacturers of the locomotives were severely criticized because of the weight, and the fact that it was necessary to use two locomotives for hauling the heavier trains. This matter of course has been explained many times. I mention it only to call attention to the improvements which have been made since the first installation, in the capacity and weight of locomotives. In my discussion of Mr. Murray's paper at Toronto, I mentioned the new type of locomotive which has been built for the New Haven Company. It has quite radical electrical, as well as mechanical, features. The general view of this locomotive is given in Fig. 1. It is sometimes called a "double Mallet type" from its peculiar truck arrangement, but it has been properly christened the "Colonial type". Each driving axle is operated by a pair of motors, which are mounted rigidly on the frame of the locomotive, directly above the axle, and are geared to a quill surrounding the axle. The quill drive is exactly the same as shown for the 071 locomotive in Mr. Murray's paper, but there is only one gear required where two are necessary for the single large motor shown on the 071 locomotive. It is a strange thing that for single-phase work at any rate two motors of a certain total capacity can be made lighter and cheaper than a single large motor of the same capacity. We have therefore applied two small motors here, where on the 071 locomotive one motor is used. This design has the following advantages:

First. Coupling two small motors permanently in series gives the effect of a high voltage motor. This reduces the sizes of cables and control losses on the locomotive.

Second. Only one gear is required where two would be necessary with the single large motor developing the same tractive effort. Both pinions on the small motors drive the same gear. This reduces the weight very materially, and also the expense of installation.

Third. The small motors are much better adapted to the space between the wheels than a large motor, because the only way to increase the capacity of the motor is to increase its diameter, and when it becomes necessary to use twin gears for a large motor, the space available between the wheels for the motor itself is very much reduced, and consequently the diameter and weight must be greatly increased. It must be noted that the total number of running parts in the motors, *i.e.*, commutator bars, brushes, brush holders, poles, etc., are practically the same whether one motor is used or two. There will therefore be no more possibilities for trouble developing in the two motors than there are for one, and cost of repairing the small motor is very much less than making similar repairs on the large motor.

Fourth. The control equipment itself, on account of having a higher voltage, is simpler and cheaper.

The weight of the locomotive as shown is 116½ tons, and will develop continuously a tractive effort of 12,000 lbs. at 35 to 40 miles per hour. It will also be used for hauling heavy passenger trains up to speeds of 50 miles per hour. The weight as given includes the complete steam boiler, water tank, and direct current control equipment. With these parts removed, the weight would scarcely exceed 108 tons, showing that a very substantial gain has been made in the design of the single-phase electric locomotives, since the first ones were introduced. This machine will haul the heaviest train on the New Haven Railroad, whether it be a 1500-ton freight or an 800-ton passenger train, and will develop a good speed with either.

The mechanical design of the locomotive is also quite novel. The two middle pairs of drivers form a rigid wheel base, and an outer driver with its pony axle forms another rigid wheel base, which leads the locomotive. The deep plate frames are entirely outside of the axles, and are connected at the ends by heavy bumper girders,, the bump being transmitted to them through the leading truck frame. The entire construction of the locomotive lends itself to lightness, as well as strength, and we expect to hear some excellent reports on the performance of this locomotive.

John W. Lieb, Jr.: Considerable has been said about the importance of power house operation in connection with the electrification of trunk line railroads, and I hope I may add a mite to the discussion in that particular direction. The power station companies, companies distributing light and power in our big cities, such as the companies in Chicago, New York, and similar communities, are, I need hardly say, desirous of getting that business. We are not very much interested in the question whether the roads operate at three-phase or single-phase, or by the direct-current system, provided we can get the current supply to them. That is selfish, I will admit, but it is also business, and it is in the line of the economical development of electric power. We would, however, urge on this question of standardization, that it is of immense importance to the companies embarking on this question, to be able to exchange current with the local large supply source, and therefore, I was much pleased with Mr. Murray's plea for 25-cycle generation, even in the case of alternating current systems.

Now, we who are engaged in the lighting and power distribution business believe that we can be of immense assistance in hastening this electrification problem, because one of the great difficulties is the immense investments that are required in accomplishing this electrification; but if the terminal companies and the railroad companies can feel that they can obtain their power supply at a cost certainly not to exceed what it would cost them, and save that enormous element of investment, which the local lighting and power companies are ready to supply, we believe that we have contributed at least one important element toward hastening this consummation.

I need hardly make a plea here for combination service, as between railway service and lighting and power service, but I will say this—that a careful study of the times of peak load between lighting and power systems shows the immense economical advantages which may accrue through a combination of these services, not only in the enormous saving of investment which will come even by so small a difference of maximum loads at peaks, of a difference in time of fifteen minutes between the railway and lighting peaks, which in the case of power plants of 100,000 kw. or more may represent a saving in investment of 1,000 or 1,500 kw., but also in the very greatly improved load factor which results from this diversity factor, and we all know what an important place the load factor has in the central station power cost economy.

Something has been said about storage batteries, and I would like to say a word as to that, and that is of the vital necessity which the storage battery is to-day in this question of absolutely certain continuity of service. I am frank to say that I believe our very large power systems, certainly those for the distribution of light and power, have a record for continuity of service which they would not have, and it would be practically impossible to maintain such a record, without the assistance of the storage battery.

It is true that the conditions of battery operation have greatly changed in the past few years. We have departed from the idea and necessity for using the battery for large current output, for continuous use, or the idea that in order to keep batteries in live condition they must be charged and discharged at minimum intervals, say once a week, or several times a month. We are satisfied now that we can obtain and maintain batteries in perfectly healthy condition by using them simply as a reserve, as an insurance, and for this purpose their value is simply inestimable. They play today an immense part in central station economy, and by having the railroads install their own batteries to assist in the distribution end especially, of course, with direct current, they will be able to bear with the local lighting companies the incidental economies and advantages which come from reducing peak demands.

I would like to make, therefore, an urgent plea for a settlement on this question of combined service, believing that, first, it will assist in the economical solution and hastening of this electrification problem, and secondly, because of the enormous advantages which will accrue to both the railway and lighting companies in the adoption of combined service.

In this particular field, I cannot hesitate for the moment it takes, to give the praise which should be due to this great institution, the Commonwealth Edison Company, in having been the leaders in this enormously important field, and having made practical demonstrations on a large scale of the advantages which were likely to accrue, and which do certainly accrue, from this combination of service.

Charles. F. Scott: I would like for a moment to compare the difference in the discussion of the railway question in the Institute a few years ago with the discussion to-day. At the Great Barrington meeting, held nine years ago, there were many railway papers presented, and many prominent engineers took part in the discussion of these papers. I have run through the proceedings of that meeting very carefully, and the one urgent question in the minds of all was this—How can we operate electric railways by supplying alternating current directly to the car or locomotive? And the solution which they thought apparently impossible was—"Where shall we get a motor? If we had a single phase alternating current motor the difficulty would be solved." A few months later was presented the paper proposing that motor. About five years later one of the most important railways in the country began operations under certain handicaps. The work was undertaken very quickly, the locomotives had to be designed and put in operation in a short time, there was not available the ten years which direct current had for its development, and they had the handicap of operating both by alternating current and direct current; nor was the motor the whole problem, for the line question, the switch question, and the generator question, came in as even more important than the motor in practical operation.

We have heard with great interest of very interesting tests which were made here in Chicago on switches, on a system on which short circuits were rare, where the high-tension circuits are protected in cables underground. On the New Haven system, with 100 miles of trolley wire in railway service, where short circuits were more or less frequent, with a generating capacity greater than in the tests here made, the solution had to be worked out while the railway was operating. That is one example of the kind of problems that come up in large work in a new field. Now we know that the alternating current will operate satisfactorily, and it is a choice between systems. The manufacturing companies have done their part, they put hundreds of thousands of dollars into this development. The problem has been crystallizing into a matter of operation. What are the operating conditions? What are the things which cannot be determined in the designing room or testing room of the manufacturing companies? The papers, such as are now presented, give records and facts which present to all the problem which must be worked out, jointly, by manufacturers, consulting engineers and railway men—what are the conditions of operation and how can they be met and by what system? Do we want to standardize? Yes, we want to standardize as rapidly as we are sure of our ground, but we want to leave open the opportunities for development. Several of these developments were suggested this morning—a mercury rectifier, the induction motor operating from single phase, and these, I believe, have been the only things looked forward to in the future. But these, as well as the single-phase motor, will all operate from the single-phase trolley, so that the single-phase system, as a general railway system leaves them open for adoption in the future. It is significant that Mr. Murray, who is in the best position to know the difficulties in operating a single-phase road, is the man who is loudest in its praise.

Frank J. Sprague: I have heard the few remarks made by Mr. Storer and also the statement by Mr. Murray. I have avoided all reference to overhead or third-rail matters in yards, advocating neither the one or the other in the brief remarks I have made. The overhead construction shown by Mr. Murray is equally applicable for direct current or single-phase current operation, so if that in his opinion is the determining feature, I am glad of it.

Mr. Storer intimated that in passing comments on Mr. Wood's paper I made some invidious comparison between the upkeep of the third-rail and the overhead structure on the West Jersey & Seashore road, and that I might have taken the trouble to speak of the local conditions. I do not know what the local conditions are. I took the paper and gave the relative costs of third-rail or overhead trolley upkeep simply as incidental facts.

E. F. W. Alexanderson: There is one phase of the subject of trunk electrification to which I wish to call attention. Mr. Murray has referred to the same by making the statement that the system was laid out with the consideration in view that the traction work at some later time would be done by induction motors.

Whether it should be considered as unfortunate or not, it is a fact that the development of the alternating current motive power for railroad, has been in opposite direction to the corresponding development for industrial and mining enterprises. The alternating current distribution system is admittedly unrivaled and the use of the same is supported by the undisputed superiority of the induction motor for all purposes where such motors can be used. From the fundamental system of power supply by induction motors has grown up a number of special developments like the single phase induction motor, the single phase commutator motor, and the polyphase commutator motor. A campaign has been going on for several years for exploiting inventions along these lines, and to define the special requirement where an induction motor cannot be used to advantage in order to find application for special apparatus in order to meet those requirements. All those machines are expensive and objectionable in many ways compared with the induction motor, but the field that must be covered by such machines is small compared with the general application of induction motors, so that the use of such machines is not considered as an argument against alternating current systems.

In alternating current practice the development has been the opposite. The most difficult problem has been attempted to begin with and has been furthermore complicated by the requirement that the a-c. equipment should also be operative on direct current. The result is that the a-c. traction system has been largely discredited. If the development had been the opposite, if the three-phase induction motor had gained an established right in the railway field, if then the single-phase distribution had superseded the three-phase, yet maintaining the constant speed induction motor, and finally the commutator had been introduced for such special conditions of traction where the variable speed characteristics are valuable enough to warrant a higher expenditure, then the various problems of railroad electrification might have appeared in a quite different light.

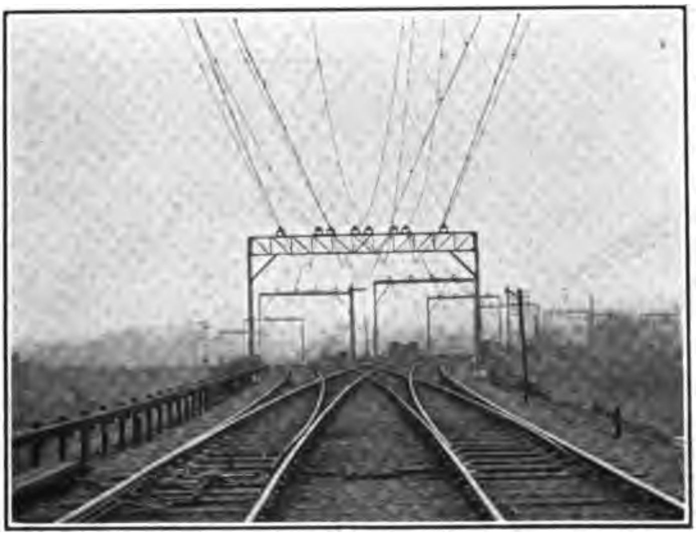
In view of Mr. Murray's statement, it is gratifying to see that he has already considered the possibility that a development of the motive equipment might be started over again on a more sound basis. It might be premature to predict that all the traction work under Mr. Murray's supervision could be carried out by induction motors, but I feel confident that the larger part of it could, with a greatly reduced expenditure both in first cost of equipment and in maintenance.

Philip Dawson (by letter): I entirely agree with the paragraph in the commencement of Mr. Murray's paper, in which he states that the religion of his paper is to preach the doctrine of universal use of the single-phase current on trunk lines and roads inclusive of terminal territory, as applied to freight and passenger operation.

Wandsworth Road

The experience I now have in connection with the electrification of the Brighton Railway which is equivalent to the equipment of over 60 miles of single track, (a large portion of which has been running since the beginning of 1909) has convinced me that there is now no longer any doubt that the single-phase system is at least as good as the continuous current system for operating suburban traffic requiring rapid acceleration, and with short distances between stopping places. This having been demonstrated by actual experience, there could be no doubt that for the electrification of any of the main line railways, the only system which could be considered is the single-phase one. No one I think denies that for long distance work the single phase is the only solution. The contention of those, who through thick and thin uphold the continuous current, is, that for short distance work the continuous current is far superior to alternating, and that therefore it should be used for this class of service, and that when long distance work becomes necessary, the single phase system should be installed in addition to it.

It may be interesting to know that we have had practically no troubles or serious inconvenience of any kind since we started service in 1909 and that with the multiple unit trains the average annual mileage per motor coach, including all our spares, and those which are being overhauled, was last year over 58,000 miles.

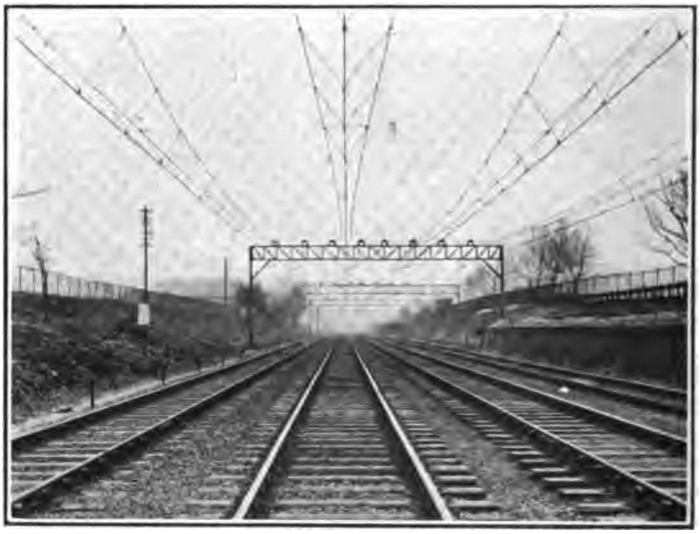


LEIGHAM JUNCTION

Our average speed with stations three-quarters of a mile apart, is 25 miles per hour. The line consists of nothing but curves and gradients and at the start, out of Victoria station, we have a gradient of one in 64 for over a quarter of a mile.

Besides this we have five sections where overhead conductors are connected to earth which thus seriously interfere with acceleration; one of these dead sections being just at the foot of the gradient out of Victoria station. Our average acceleration throughout the whole period of acceleration from 0 to about 35 miles an hour is one mile per hour per second.

We wished we could increase this by increasing the size of motors and the capacity of the power station; experience, however, has shown that the acceleration I originally selected is sufficient, and the increase in traffic since electrification started has been over 150 per cent and it is still increasing. This is a very important fact particularly if we consider that the South London line is intersected and paralleled by a very large number of electric tramways, that the saving in time is only about 10 minutes, and that the fares on the electric railways are nearly double those on the tramways.



Wandsworth Common

In connection with the experience which has been obtained with continuous current electric railways and single phase current electric railways, there is no one who has greater right to speak than Mr. Wittefeld, the Chief Engineer of the Prussian Government Railways. He has constructed and operated both continuous-current and single-phase railways. The continuous-current is one in Berlin going to Lichterfelde and worked by most up-to-date continuous-current apparatus and having very heavy suburban traffic. The single-phase line is that at Hamburg, both having now been worked for some years, and Mr. Wittefeld is the only engineer and railway official I know who has this dual experience at his disposal.

His letter addressed to me in connection with my paper before the Institute of Civil Engineers states:

"Your satisfactory experience regarding single-phase traction for working surburban lines, entirely agrees with ours on the Blanknese line. It can no longer be doubted, in accordance with my own personal experience, that for suburban electrification the single phase system is at least as good as the continuous current system. The experimental results for long distance traffic with very heavy as well as fast trains on the section Dessau Bitterfeld on this system have been most satisfactory. The large electric locomotives driven by connecting rods have surpassed all expectations. It is now my unshakable decision that the single phase system with the experience we have now gained, is the only system which can generally be used for electrification of main line railways. No experienced railway engineer, who wishes to be considered far sighted, can, I think, come to any other conclusion."

Besides the above, Dr. Wyssling, who was head of the Swiss Commission appointed to investigate the question of railway electrification, also wrote to me in connection with my paper. He said, "That according to his conclusions and that of his committee the single phase system is the one which is most suitable for heavy railway electrification, because the transmission and contact system is the simplest, because of the great variations in speed possible, and because it is the cheapest to install."

I am sending three views of the line which may be of interest.

W. N. Smith (by letter): As matters are now in the trunk line electrification field, installations upon a large scale are so few, that Mr. Murray is in the unique position of having had more practical experience than almost any other engineer in his special field—which gives him a distinct advantage over his critics, both past and present.

This installation in general is an illustration of the principle, that in any new departure the engineer can expect to learn a vast deal about structural and operative details as he goes along and at the same time can be confident of being generally upheld by results, in the decisions he had to make when planning the work.

It may be well to keep in the foreground Mr. Murray's definition of a trunk line. About a year ago, before the New York Railway Club, he defined his conception of a trunk line as "A line connecting large cities which are separated at some considerable distance. The portion of a trunk line which lies in the immediate vicinity and the outlying districts of those cities will carry upon it a suburban traffic."

Without criticising this conception, it might easily be implied from Mr. Murray's present paper that he considered as trunk lines only such roads as might be in the same class with the New Haven, namely, a main trunk of from two to four or six tracks, with numerous single and double track branches or net works and a heavy suburban service. It is a well known fact that some of the most important railroad lines connecting the large cities of the country are single track lines, particularly in the less densely settled portion of the country, though in some sections the most important roads are making progress in double tracking. Nevertheless, there are many roads that are not likely to double track for at least one more generation, and yet are, in the general opinion of themselves and the public, entitled to be called trunk lines, as is further borne out by the fact that all rolling equipment upon steam railroads, whether main lines, branches or otherwise, is interchangeable; and so far as structural considerations are concerned, trunk line conditions are usually conceived to include branches or side lines, whether located so as to be fit for electrification, or not; as well as the main arteries of traffic which have already reached or may ultimately reach that density of traffic which determines the economic suitability of electrification. The Spokane & Inland Empire Line, for instance, is more than 120 miles long and though it does not connect Spokane with any city even approaching Spokane in size, it is still fitted for handling standard trunk line equipment and actually does handle railroad freight trains of a respectable size with the system of electrification advocated by Mr. Murray, though at lower trolley voltage. Its peculiar situation, as respects cost of providing power for operating, is said to have favored the adoption of electric motive power, as distinct from considerations of traffic density, thus making it a special case. It would not be called a main trunk line, for instance, in comparison with the Northern Pacific; but the adoption of that equipment which is most suitable for long lines with heavy trains brings it into the trunk line class, so far as electrification is concerned.

To summarize, it seems to me that the accomplishment of trunk line electrification is broadly determined, first of all, by the general characteristics of railroad rolling stock used for transportation, and in a secondary degree by geographical location.

Mr. Murray states that the criterion of financial return is "how much it costs to produce the necessary tractive effort" in the several types of locomotive mentioned. The writer believes that this statement of the problem, while it appeals to one's engineering sense as probably true, is still so vague as not to carry conviction. Rightly or wrongly, the ton-mile or the car-mile are the units most commonly used for comparing transportation performances—as is well shown by Mr. Murray's own data. It seems to me that until some new unit is invented which will more correctly express the desired relationships, the ton-mile or car-mile should be used as explicitly as possible in making such comparisons. Annual reports of the largest steam railroad systems commonly include a great deal of statistical information that is or can be referred to a ton-mile basis for comparison, and the present Interstate Commerce classification enables the compilation of a good deal of interesting information regarding the various costs of train performances per ton-mile, if one will take the trouble to dig it out of a comprehensive report.

I am impressed with the magnificent performance of the New Haven system as regards the small amount of train delays; but it should not be forgotten that this particular system has four tracks and an arrangement of feeder section switches on the anchor bridges which enables sections to be readily isolated in case of trouble, thus preventing many delays providing the trouble is discovered soon enough. It is very doubtful whether any single track line with an equivalent train mileage per mile of single track could exhibit such a clean record, as the difficulty of reaching and remedying trouble without interfering with train service on a single track is vastly greater than on a 4-track system. The high grade insulation which Mr. Murray advises to be used as the cheapest means of securing satisfactory trunk line operation, is even more necessary on a single track than on a 4-track trunk line; and this is as true of strain insulators as of the straight line insulators. Mechanical sufficiency in every part is equally important for the same reason, and the various details mentioned by Mr. Murray as constituting distinct mechanical improvements, should therefore be all the more carefully followed in single track line construction.

Referring to Mr. Murray's remarks on storage batteries for trunk line electrification, he is undoubtedly correct for trunk line electrifications approaching the magnitude of the New Haven Railroad. But cases have arisen in the past, and probably will from time to time in the near future, where the use of a storage battery offers some economic advantages. Here, again, the Spokane & Inland Railway furnishes an example of trunk line electrification under special conditions which made a battery adjunct advisable, even with the extra conversion losses from continuous back to alternating current when discharging. The fact that the current for this system is generated by water power will go far to explain the reason for the adoption of the battery in this instance.

In view of the numerous failures of the early types of storage battery in street car service during the early development of electric traction, it may at first appear idle to some, to even consider the possibilities of the storage battery for direct propulsion of cars in trunk line work, but the gradual improvement in reliability that the lead battery has developed in electric vehicle service; the development of the nickel-iron-potash battery by Mr. Edison; and the successful application of both these batteries to light railway work during the past year, in New York City, Philadelphia and Washington, together with the successful experiments in the operation of branch lines of the Long Island Railroad and the Erie Railroad, each of which now has a battery car in operation, all indicate that we are not yet at the end of our resources as to the choice of an electric propulsion system for at least some types of steam railroad service. The developments of the past year have been on a small scale, but are most encouraging, and indicate that if both electric tramway and steam railroad engineers are willing to reconsider their previous conceptions as to design and weight of car bodies, anti-friction journal bearings, motor capacities, gear drives, and battery maintenance, in connection with the possibilities which battery car propulsion offers in the production or purchase of electric power at a high load factor, (which minimizes power-station or sub-station investment and operating expense, or enables the purchase of off-peak power at minimum rates), they will be enabled to view the economics of heavy electric traction from a new angle.

This applies more especially at the present time to electric trunk-line branch service; the next step will be in the direction of battery traction for suburban service at moderate speeds.

The more recent successes of storage battery traction have been largely due to the fact that the cars thus far constructed have been practically built around the battery, and are of very light construction, with anti-friction bearings, thus reducing both the tons to be transported and the pounds per ton resistance of the car journals. The writer believes that the problems to be solved in connection with the development of storage battery traction for trunk line branch and suburban service are much more of a mechanical nature than electrical, and reduce ultimately to the question of how light it will be possible to construct a car, suitable for operation on steam railroad tracks, that shall be regarded as sufficiently strong to insure its own stability and the safety of the passengers against all shocks that can reasonably be expected, and can carry enough battery for economical operation in the service it is desired to handle.

These questions will be settled by the judgment of railroad mechanical experts and will doubtless require much experimental working out; nevertheless, I believe that the field for exercise of ingenuity in this line will be cultivated, though it may be a few years before it has acquired the status now enjoyed by the several typical systems involving working conductors. The fact that power in any necessary quantity can now be purchased at the lowest possible rates for charging battery cars during those periods of the twenty-four hours when they are most likely to be idle, together with the entire abolition of working conductors for the tracks, which eliminates the question of interchangeability of different working conductor systems, constitute arguments that will be likely to appeal to steam railroad men. Such possibilities are, of course, predicated upon the assumption that the storage battery of the future will prove to be as reliable and subject to no more depreciation per car mile than modern types of motors and generators. Should this development eventually come into being, and should steam railroad officers permit themselves to utilize lighter car bodies, we will then have available one more method for utilizing electrical apparatus to supersede the steam locomotive, in some situations, at a lower first cost than is possible with the present systems of instantaneous transmission of railway power.

Railroad electrification is at the present time much desired by the public at more than one large terminal. Whatever system of electrification be followed, the probability is that the suburban service of almost any railroad would be the first to be electrified, thus resulting for a time in a mixed steam and electric system. The initial electrical equipment must, therefore, operate in some degree interchangeably with the existing steam equipment, and all the circumstances surrounding steam operation must be given consideration as affecting the first cost, operation, and general durability of the proposed electrical equipment.

Mr. Murray has fulfilled the engineer's function of getting superlatively good results under certain difficult conditions with the electrical apparatus now available for such work. I must confess, however, to a degree of caution when it comes to declaring the state of the art at this time as so complete, that all work in the immediate future should be based upon present practice, even on the remarkable showing made by the New Haven Railroad installation. I shall not be surprised if, by the time that railroads in general are able to pay for electrification on a large scale, some methods less costly, both as to investment and daily operation, will have been devised for accomplishing the desired results, especially in those terminal situations where the need for steam railroad electrification is now most pressing.

B. F. Wood: In view of the limited time at my disposal I shall confine my remarks to the suggestion made by Mr. Lieb that power should be purchased from power companies rather than generated by the railroad companies at their own plants.

By reference to the table showing Cost of Construction it will be noted that the investment in power station and transmission line is nearly a quarter of a million dollars. With this amount included the net earnings during the year 1910 were sufficient to make a return on the total investment for electrification of about 8½ per cent. If power could have been purchased at rates prevailing in Chicago for such service, the same net earnings would have shown a return of nearly 9½ per cent on the lesser investment necessary; showing conclusively that the power station is not earning the average rate of return.

At the time of the electrification of the West Jersey & Seashore Railroad it was not possible to purchase power for such operation and it was therefore necessary for the railroad company to build its own power station.

Again, the rates for power in some cases have not been based upon the cost of furnishing the service but have been fixed with relationship to the charges for other service differing in character and in a good many cases such rates have been prohibitive.

The responsibility, therefore, for the railroad companies building power stations rests largely with the power companies and if they are to take over this business they must fix their rates on a basis that will give a return on investment necessary for such service and not on the average cost of power.

C. P. Steinmetz (by letter): Mr. Murray's paper appears to me very interesting and valuable for the complete information which it gives on the practical experience of a number of years operation of a section of a trunk line railway, electrified by the single phase alternating current system.

Especially important appears to me the conclusion which Mr. Murray reached as the result of actual experience of several years successful operation, that 25 cycles is the proper frequency for railway electrification. This entirely agrees with my opinion, which I expressed here at a previous occasion some years ago: " If the single-phase commutator motor can not be designed and operated at 25 cycles, it can have no future and no right of existence." No odd frequency, as 15 cycles, or 8 cycles, can be seriously considered, especially after the unfortunate previous experience. In some special instance, a railway section isolated from all sources of electric power supply, some odd frequency as 15 cycles may appear to have some advantage without any immediate disadvantage, just as 40 cycles appeared advantageous for mill work; but sooner or later the disadvantage of the odd frequency will become apparent, and it would be fortunate if then it would only mean scrapping the odd equipment, as is being done in Southern 40-cycle cotton mills, and if the odd frequency has not spread so as to be irredeemable, as 50 cycles in Southern California and 40 cycles in the upper Hudson River development.

John B. Taylor (by letter): Under the heading of Power House, Mr. Murray points out the advantages of employing three-phase generators rather than single phase, even though the bulk of the energy is supplied to a single phase trolley system. This naturally results in unbalanced voltage which is a point of greater or less importance depending on the amount and fluctuations of the unbalancing, as well as on the types and relative capacities of the pieces of apparatus connected to the three-phase system. In general, polyphase machinery, such as induction motors, synchronous motors and rotary converters, connected to an unbalanced system, will to some extent improve the balance at their own expense, so that such pieces of machinery must have their rating changed or the amount of heating will be greater than the heating would be for the same output on a normal balanced system. How serious this curtailing of rating or increase of heating will be, is, of course, a matter dependent on the particular conditions prevailing on the particular system under consideration Bearing on this point, Mr. Murray makes one statement that seems open to question: " . . . such (unbalanced voltage) as remains is easily compensated for by arrangement of transformer taps in the substations reducing the three-phase current from high to low voltage for motor or synchronous converter application." While it is a well recognized proposition that any polyphase system can by suitable transformer connections be converted to any other polyphase system, it is not evident that the mere placing of taps on transformers will convert an unbalanced three-phase system into a balanced three-phase system, since any differences in the voltages must be accompanied by changes of phase relation. While suitable transformer taps may be selected so that the voltage from each individual transformer can be given a desired value, these three voltages cannot be interconnected to form a typical three-phase system, on account of the distorted phase relation. It is of course possible to obtain both the desired voltage correction and desired phase relation by the general principles of phase transformation, that is, connecting in series two or more windings having different phase relations. Such interconnection of phases naturally involves specially constructed transformers and some complication of wiring to obtain the desired result, which cannot be accomplished by transformer taps alone.

R. E. Hellmund (by letter): There are a few statements in Mr. Alexanderson's paper which, while perfectly correct, might be misleading to the casual reader of the paper. Mr. Alexanderson states " The output of the converter must be substantially one-half of the polyphase capacity of the motor." He also says " The single phase capacity of the converter corresponds to the input of one phase of the motor, or one-half of the total output."

The following statement, which is also correct, might give to some readers, a better idea about the size of the converter— " The polyphase capacity of the converter is exactly the same as the polyphase capacity of the motor." In other words, if the two machines would have the same speeds, they would have to be exactly the same size.

In comparing the phase converter with the motor-generator set, Mr. Alexanderson seems to favor the phase converter somewhat. The generator of a motor-generator set is a polyphase machine and its size would, therefore, be the same as that of the phase converter. The driving motor being single phase would be about 40 per cent larger. Even considering that a motor generator set requires an exciter and that the converter is a squirrel cage machine, I believe that while a comparative weight of 1 to 4.5 may be obtained under special condition, a ratio of 1 to 3 or 1 to 3.5 would be more correct in the average case.

Mr. Alexanderson's statement that the converter will add only 26½ to 30 per cent to the weight of the motor, of course, is correct under certain assumptions. This question depends, however, entirely upon the possible relative speeds of the motor and the converter. The saving accomplished by the fact that the converter is not a driving machine, is probably not very large in most industrial applications. It is my experience, that the electromagnetic stresses during the starting period of induction machines is usually the governing feature and will not permit a light mechanical structure, except in case of a very large air gap, which in turn, would spoil the power factor. Nevertheless, the system has certain advantages and its application will be well worth considering in some cases. While no mention of the possibility of using the system for railway work has been made in the paper, this question might be of interest. Since the converter adds 25 to 50 per cent to the motor weight, the total equipment will be as heavy or heavier than the straight single phase commutator motor equipment.

The possible omission of the transformer on the locomotive, which is one of the main advantages of the straight three-phase operation, will, in most cases, not be possible with the proposed phase converter because the equivalent single-phase line voltage would have to be considerably larger. In fact, it is liable to pass the voltage limit for which the converter and the motors could be safely and economically insulated. A transformer on the locomotive will, therefore, be required in the majority of applications.

The application of the system for general railway work seems, therefore, not very advisable, since the introduction of an intermediate revolving machine would reduce the reliability and since the constant speed feature of the induction motor is a disadvantage in general railway work in this country.

In such cases, however, in which three-phase operation is desirable for some reason or other, the proposed system might be considered. Especially in cases where the distances are large, while the number of locomotives is small, some saving in first cost over the straight three-phase system, might be accomplished.

While the rolling equipment will be, of course, considerably heavier as well as more expensive than the straight three-phase equipment, the saving made by the cheaper overhead construction may possibly more than offset this disadvantage in some cases.

In connection with railway work, I would like to bring up the question of regeneration and ask whether this point has been investigated to any extent. It might also be well to ask the question as to what would happen if the power should be off for a short interval of time, which would permit the phase converter to reduce its speed to any extent. It seems that in such a case, there is danger of the phase converter falling out of speed, especially if it is designed for as high an efficiency as Mr. Alexanderson proposes.

While it is quite possible to obtain a good efficiency with a phase converter, it seems rather difficult to obtain at the same time, good starting conditions for the same, as well as a strong tendency to pull back into speed whenever the power goes off.

In regard to the power factor, it might be said that the total power factor probably would be rather low in spite of the fact that the power factor of the converter may be as high as 95. If we assume for instance a motor with a power factor of 90 and a phase converter with a power factor of 95, we obtain a combined power factor of only 77.5. The same combination at half load would have a power factor of 45 to 50. This is about the most favorable condition which may be obtained. In many cases, especially in case of the lower speed of a two speed motor, the power factor may come as low as 60 or even lower at full load.

In fact the power factor conditions for the phase converter system are very much the same as for two induction motors operating in cascade connection in so far as two machines have to be magnetized. A comparatively low power factor will, therefore, be inherent to the system. Special means for correcting the power factor would further complicate the system, so as to make their use hardly worth while considering in connection with railway work.

E. F. Alexanderson (by letter): In answer to the questions brought up by Mr. Hellmund regarding the system of single-phase operation with phase converters and polyphase motors, it can be stated in general that the system is applicable for regenerative breaking in the same way as the three phase system, and that it has been demonstrated that the phase converter has no tendency for falling out of step if the power is interrupted. As soon as the power circuit is broken all the magnetic fields disappear and the phase converter continues to run light, being retarded only by friction and windage. It therefore would take a considerable time for it to slow down to any great extent. However, it was demonstrated that the speed might drop to $\frac{1}{3}$ of full speed, and yet the phase converter would come up to full speed as soon as the circuit was re-established.

The figures given in the paper regarding the relative weight of motors and phase converters are of course in no way to be considered as general—they refer to a specific case of locomotive equipment, which appears to be particularly suited for heavy mountain railway work. Any comparison between the phase converter system and the single phase commutator motors must therefore be considered from this point of view. It can be stated in the case that has been studied that the phase converter system gives a much lower weight of locomotive than the single phase commutator motor. The controlling feature is not so much the relative weight of the auxiliary apparatus as the space factor of the motor itself, which determines the type of locomotive which may be used.

Regarding power characteristics the indications are that the average power factor will be as good as or better than the corresponding single phase commutator motor.

Edwin B. Katte (by letter): The contribution to the discussion of Mr. Murray's paper which I have to offer is based upon some direct current experience, and in order to avoid the impression that I favor direct current to the exclusion of all other systems for trunk line electrification, I will preface my remarks by saying that I believe any steam railroad can be equipped for reliable electric operation with either of the three commonly discussed systems; but that one of these systems will more satisfactorily meet the special conditions of each case, and that at the present time no one system of electrification has been developed to satisfactorily meet all the conditions of every trunk line problem.

It is not a question of direct-current, single-phase or three-phase alternating-current that we should be discussing, but rather steam *versus* electric operation, and until we do confine ourselves to the real issue and can show economy in electric operation, we cannot expect to interest steam railroad men as a whole.

Electrification has proved itself entirely reliable on many steam railroads and in some cases has demonstrated a saving in operating expense. However, I do not know of a single instance in which it has been shown that this saving is sufficient to cover the additional fixed charges, and I hazard the opinion that no trunk line electrification will prove economical as compared with steam until an entire steam locomotive division has been electrically equipped.

Electricity, at the present time, must be considered as more or less of a luxury or as a means to some end other than economy of operation. The great trunk line terminals in New York City would not have been possible were it not for electricity, and the operation of the Detroit River and the Sarnia tunnels would scarcely be safe were it not for electric locomotives; in such cases as these the high cost of electricity is justified. But on the other hand, if a city or other property, through which a steam railroad passes, is to be improved by the elimination of the nuisance of steam locomotives, the cost of this property improvement should be shared in by the city, state or individual in a manner similar to the present practice in the matter of grade crossing eliminations.

With much interest have I read Mr. Murray's statement, to the effect that " we have made electrification in its various forms work, we can now make it pay," and although I have carefully perused every page of his paper, I have failed to find the last statement justified, except in his claim that—" to make electrification pay, he (the electrical man) must be able to reproduce the four classes of steam tractive efforts by electricity, with a total investment, the interest on which must be carried by the economy to be effected over steam operation." Then follow data about water consumed per ton-mile of steam trains and watt-hours per ton-mile for electric trains, concerning which you are all more or less familiar, but not a word regarding the relative cost per ton-mile of steam and electric trains in similar service. It is this cost data in which we are so vitally interested, and this I had hoped to find in Mr. Murray's analysis. Here I may add that cost figures for comparative performance on the New York Central system are not available for the reason that the service is still mixed steam and electric; steam locomotives operate over electrified tracks and multiple-unit trains are hauled a large portion of their run by steam locomotives due to the still uncompleted condition of the Electric Division.

In Fig. 38 Mr. Murray has reproduced several speed-time curves for single-phase locomotive runs and has computed the current consumption in watt-hours per ton-mile for local and express service on the New Haven Railroad. A comparison of current economy based upon watt-hours per ton-mile for different systems on different railroads is not very conclusive because of the effect of grades, curves, station stops, schedule speed, etc., but as an indication of what might be expected in comparing direct-current and single-phase locomotives in the same service, I have selected locomotive runs on the New York Central direct-current system as nearly the same as those given by Mr. Murray as the train schedule will permit, and the results are tabulated below:

LOCAL TRAIN SERVICE

Items	Single-phase loco.		Direct current loco.	
Direction of run	W. bound	E. bound	N. bound	S. bound
Average grade	+0.053%	-0.053%	+0.129%	—0.129%
Train number	213	216	333	1016
Date	2/11/11	2/11/11	6/6/11	5/31/11
Run between	Stamford-Woodlawn		G. C. Term.-No. W. Plains.	
Train weight, tons	316	285	266	250
Length of run, miles	20.6	20.6	23.9	23.9
Time of run, min	55.8	55 8	61.8	62.8
Schedule speed miles per hr	22.1	22.1	23.2	22.8
Number of stops	13	14	20	18
Stops per mile	0.63	0.68	0.84	0.75
Watt-hr. per ton-mile	85.4	74.2	81.6	59.4

EXPRESS TRAIN SERVICE

Items	Single-phase loco.		Direct current loco.	
Direction of run	W. bound	E. bound	N. bound	S. bound
Average grade	+0.053%	-0.053%	+0.129%	—0.129%
Train number	9	16	1005	1004
Date	2/11/11	2/11/11	5/9/11	5/29/11
Run between	Stamford-Woodlawn		M. Haven Jct.-White Pls.	
Train weight, tons	477	493	432	434
Length of run, miles	20.6	20.6	17.11	17.11
Time of run, min	27.6	25.2	23.3	23.4
Schedule speed, miles per hr	44.7	49.0	44.1	43.9
Number of stops	0	0	0	0
Watt hr. per ton-mile	35.0	30.0	29.2	17.6

From the tables it will be noted that the trains selected for comparison are quite similar in weight, schedule speed, number of stops, etc., for each class of service, however there is some difference in the grade of the two railroads, the New Haven having an average descending grade of 0.053 of one per cent from Woodlawn to Stamford, and the New York Central an average ascending grade of 0.129 of one per cent from Grand Central Terminal to North White Plains. For this reason the comparison is made of trains operating in both directions and in all cases, both for express and local trains up or down the grades, the saving in current consumption is in favor of the direct current locomotive.

COMPARISON—ELECTRIC OPERATION
NEW HAVEN R.R. AND NEW YORK CENTRAL R.R. CO.
TRAIN MINUTE DELAYS PER MONTH

	New Haven R.R. Co.				New York Central R.R. Co.				
Month	Power houses	Trans. lines	Elec. loco.	Total	Power houses	Line S. S. 3d R.	Elec. loco.	Total	Loco. miles
1908									
July.......	0	2100	1183	3283	0	10	30	40	86922
Aug.......	132	1642	407	2181	0	33	45	78	89670
Sept.......	0	942	224	1166	0	0	18	18	89324
Oct........	0	2140	343	2483	0	42	30	72	89561
Nov.......	139	103	405	647	0	0	7	7	83822
Dec........	179	194	240	613	0	0	35	35	89738
Total......	450	7121	2802	10373	0	85	165	250	529037
Average per month...	75	1187	467	1729	0	14	28	42	88173
1909									
July.......	0	170	153	323	0	10	45	55	95482
Aug.......	0	548	97	645	0	54	154	208	91160
Sept.......	0	0	219	219	0	7	86	93	93688
Oct........	54	204	124	382	0	0	6	6	94893
Nov.......	0	42	95	137	0	18	27	45	89504
Dec........	0	55	315	370	0	8	12	20	91082
Total......	54	1019	1003	2076	0	97	330	427	555809
Average per month...	9	170	167	346	0	17	55	71	92635

SUMMARY

Total Train Minute Delays for Six Months.

New Haven R.R. Co....................................	1908—10373	1909—2076
New York Central Co..................................	" — 250	" — 427

N. Y. C. increase was due to an epidemic of defective fuses on locomotives. Of the 427 minutes delay, 234 were due to defective fuses.

There is no data given by Mr. Murray for converting the watt-hours per ton-mile into dollars and cents to cover all fixed and operating expenses for the entire electric service, and therefore the relative cost of steam and electric operation cannot be determined, and while there may be a saving in operating expense it is not known whether or not it is sufficient to cover the additional fixed charges incurred by the electrical installation.

The statistical record of single-phase operation gives ample proof of the improved conditions of that system; the reduction in train minute delays for the last six months in 1908, namely from 10373 to 2076, in the same months of the following year, is considerable. On the New York Central Electric Division, the train minute delays due to electric trouble for the same period in 1908 was 250 minutes and in the following year 427 minutes, of which 234 minutes delay were caused by an epidemic of defective ribbon fuses which were responsible for more than one-half of the delays before they could all be removed from the electric locomotives.

Mr. Murray points with justifiable pride to the single-phase locomotive performance of 15,700 miles per one locomotive failure. A similar good record has been made by the direct current locomotives, as shown in the New York Central record for March, 1911, of 26,655 miles per one engine failure; the total electric locomotive miles for that month was 106,622.

Again Mr. Murray refers to the single-phase electric locomotive record for reliability, and states that in November, 1909, there were 66,000 locomotive miles performed with but three minutes delay and informs us that upon such ground his Board of Directors stood in ratifying the single-phase system. A better monthly record has been made by the direct current locomotives on the New York Central system, the exact mileage being 101,765 made in April last, the single train detention being of four minutes duration, caused by a broken draw bar knuckle which contained a hidden flaw in the casting. Last month, that is May, 1911, the locomotives performed an average mileage of 112,893 per one train detention of five minutes caused by a defective air brake hose.

Little is said in the paper of the power station for supplying a single-phase system and nothing about its cost of operation; the storage battery is dismissed as a thing of the past, yet both have a very direct bearing on the cost of generating current, which after all is the main source of economy—or expense—in any electric traction system. It is well known that to generate current on unbalanced phases is more costly than on an equally loaded three-phase system; and aside from the insurance feature of batteries, their economical effect in equalizing the load on power stations has frequently been demonstrated. This has again been evidenced in the low cost of generating current at the Port Morris power station of the New York Central Company, where for some time the average cost to generate current has been about one-half cent per kilowatt-hour with coal costing approximately $3.00 per ton. It would be an interesting comparison if Mr. Murray would tell you what it is costing to generate current at the Cos Cob power station for the single-phase system.

It is encouraging to note that the many electrical and mechanical changes in the original New Haven locomotives, which Mr. Murray described in his former paper, have resulted in more reliable operation; this, however, should not be the only index of satisfactory results. The successful electric locomotive should not only be reliable but its maintenance in such condition must be at a low cost. The inspection, repairs, renewals and other maintenance of the New York Central electric locomotives during the first four years of operation have averaged between three and three and a half cents per locomotive-mile for all classes of service. It would be interesting if Mr. Murray would publish similar maintenance costs for the New Haven locomotives.

There is much in the paper concerning the additional weight of the New Haven Company's single-phase direct current equipment. This feature has been criticized before now by some engineers who have wondered—in the light of the knowledge that direct current would have to be used by the New Haven Company for a considerable portion of its mileage—why such a complicated and heavy equipment was ever adopted. No figures were then available to prove that it was more economical or reliable than the lighter and less complicated direct current apparatus, and none have yet been produced.

The figures given for the first cost of the single-phase trunk line electrification system are so very general in character and the range between the high and low estimates so great that no comparison can be made with the cost of the direct current system. However, the impression derived from the unit costs given is that the direct current system would be considerably less expensive, and this impression is in a way substantiated by a comparison of the estimates submitted last Fall to the Joint Metropolitan Committee in Boston by the New Haven Company for single-phase and by the New York Central Company for direct current electrification, wherein the average cost for single-phase electrification was $71,000 and for direct current $59,000 per mile, including all items entering into the first cost of the change of motive power.

Mr. Murray's final remarks are not to my mind conclusive; he states that his paper is not an argument for the single-phase system, that statistical records of first cost and operating expense make such a course unnecessary. No such records of first cost or of operating expense have ever, to my knowledge, been given to the engineering public, and such meager results as are recorded in his paper pertain to but 85 single-track miles of main line now in single-phase operation on the New Haven Railroad between Woodlawn and Stamford, while on the other hand, more reliable operation is to be found over the 126 miles of main line on the New York Central Railroad Company's direct-current system.

My purpose is not to argue the adoption of the direct-current system as opposed to the single-phase system, but to point out as forcibly as I may that the direct-current system has thus far made a better record than the single-phase, and therefore at least two systems of electrification are available for successful trunk line operation, and to urge electrical engineers to strive to prove the advantages and economy of electricity over steam as a motive power and leave the selection of the system to be determined by the requirements of each specific case.

H. Graftio (by letter): Although the New York, New Haven & Hartford Road's present electrification was proved to be a complete success, I cannot agree with Mr. Murray's conclusion and doctrine of the universal use of the single-phase system on trunk lines.

In my opinion one cannot possibly avoid the question of relative costs and merits of electrification by various systems (in hand and to come) for various specific conditions of the lines themselves and of the traffic to be handled on them, and one cannot substitute these very complex questions by the motto: "As electrification of trunk lines is now practically at hand, what is the correct system for all?"

" No system yet at hand is the correct system for all " would be in my opinion the only possible answer to the question, unless one be satisfied with very poor average.

And as regards the recommendation of the single-phase system, among others in hand, (which also proved to be very successful in the respective cases where they are used) to be the universal system, it would really mean too heavy a sacrifice for the numerous cases of trunk line electrification, where *we really can expect* now to see electric traction advantageously substituted for the existing steam traction.

I am by no means adverse to the single-phase system, or an advocate of some other system, but I do consider that one cannot forget the results obtained, for instance, in the recent Pennsylvania electrification with the direct-current system, or the really wonderful performance of the three-phase system used on the Italian lines and among them on the Genova Busalla trunk line.

It seems to me that the whole confusion in the so much talked of question of one single universal system of electric traction for trunk lines is the outcome of one fundamental deviation in pure logics. One very often refers the idea of electrification to entire systems of trunk railroads. So far and while one is reasoning in this general and abstract way, one might be perfectly justified in advocating some single universal system, and it is possible that the single-phase system might be, so far as we stand now, the best suited for such a general purpose, or might not be.

We have had the occasion to hear this same reasoning expressed by some of the reporters at the International Railway Congress held at Bern in July 1910, and so far as the hypothetical case was considered, these reporters were perhaps in some way justified. But the same reporters on the basis of very complete studies of electrification done for Bavaria, for Austria and for

Switzerland, informed us that the electric traction is in such a state as to advantageously supplant the steam traction on trunk lines in two cases, *viz.*:

1. If the cost of energy be less than so many pfennigs or hellers per kw-hr.

2. If the density of traffic has surpassed such and such limits.

Considering the cases mentioned, we see that even for Bavaria and for Austria (and for Switzerland too), whose representatives were precisely the reporters mentioned, practically only two categories of trunk lines *can stand* electrification versus the existing steam traction at all, and those are: mountain divisions of trunk roads sometimes connected with a few short flat divisions adjacent to these mountain divisions and with cheap sources of energy in the vicinity, or suburban sections of trunk roads adjoining large cities with a sufficiently dense traffic on them.

And precisely for these special cases of real practical possibilities of electrification, other systems, such as the three-phase and the direct current come out as more economical and more suitable for purely technical reasons than the single-phase system. This has and can be easily demonstrated by figures for each of these two special cases.

What remains then of the electrification of entire systems of trunk railroads, advocated as the chief argument for the selection of one unique system of electric traction? Nothing. And what is the weight then of considering a unique and universal system of electric traction? Nil; unless speaking of phantoms and dreams, because we cannot underestimate the present Queen of our trunk railroads—the modern steam locomotive, which is and will remain for a long time to come the cheapest and the best suited for innumerable kilometres of our existing railroads, and because we also cannot overlook results obtained by other systems of electric traction.

On the other hand we are progressing so rapidly in the art that nobody can pledge for ten years in advance that some other system will not come forward in the meantime, which would make competition for any of the existing systems hard.

Extrapolation has been always condemned by mathematicians, and in the case of electrification of entire trunk systems, or even lines, where millions are to be spent and where the directors of a railroad company, or the respective governments may ask for some specific explanation as to the return each year of a percentage on some of the money spent, it seems that engineers must be even more careful in this respect than mathematicians.

Let me remark also that, with the exception of motor car trains suited for local traffic, in the long distance service where heavy trains will have to be hauled by powerful electric locomotives, it really will not take more time or give more trouble to replace, at the respective junction stations, a single-phase locomotive by a three-phase one, for instance, or *vice versa*, than is being taken now in changing one steam locomotive for another.

The verv small complications in the distribution system, that may come out of this (or may not), are not worth mentioning now and cannot seriously be taken into consideration as a reason to overlook much more serious circumstances, such as economy and technical suitability.

The conclusions reached at the Bern Congress on the question of " systems " of electric traction seem to confirm in the fullest way the above opinion.

Clause No. 2, of the conclusions of the Bern Congress, accepted by the immense majority of the railroad men and electricians of all countries, both of Europe and of America, that were present and participated in the discussions, says: " There are various systems at hand and the selection of one or another system is dependent on its respective suitability in each case."

So better let now each system develop and fight for its own, as before, in finding more and more of the convenient field for its respective development. The fittest will win.

Gisbert Kapp (by letter): Mr. Murray has done good service to the cause of electrical engineering generally in showing that electrical working of main lines is perfectly reliable. Apart from the satisfaction which every engineer will feel at the success recorded in the paper there are two broad conclusions to be drawn from it. One is the importance of treating electrification not piecemeal, but as one organic and comprehensive change and the other is the importance of standardization. The electrifications carried out hitherto in Europe were mostly tentative and piecemeal work. Under these circumstances the fixed charges on powerhouse and lines and the low load factor of the powerhouse must seriously hamper the economic advantages which can be obtained if the working is extended to all classes of traffic including yard work. Mr. Murray's paper brings out the economical advantage of treating electrification as a matter of general and not partial application. This is also the experience in Europe where not only passenger, but also goods traffic is worked electrically, though the extension of electric working to yards has not been carried out so fully as on Mr. Murray's lines. The tendency is however that way also here.

The other broad conclusion, namely the desirability of standardization, is also fully recognized in Europe, but when we come to details we get onto debatable ground. Five years ago the Swiss Government called together a committee to study this question, but although reports were issued there is at present no such thing as standard practice in European railway electrification. Of the three postulates in Mr. Murray's religion, namely type of current, pressure and frequency, only the first may be considered as a standard with us. It is true that the Italian Government has adopted three-phase current for some portions of main lines, but there were special reasons for this decision and the Italian Government engineers have by no means closed the door on the single-phase system. Mr. Verola, the chief engineer to the Railway Department, stated in a letter to me that it is highly probable that other lines will be electrified single-phase. All the new main lines electrified or to be electrified on the Continent are on the single-phase system and the two examples of main line working we have in England are also running very satisfactorily on this system. We may therefore take it that Mr. Murray's suggestion as to type of current will be readily adopted, but if we come to the questions of pressure and frequency we find the most bewildering variety in present practice. In England and Prussia most lines are worked at 25 cycles, while Italy and the Duchy of Baden have adopted 15 cycles as a standard. The Swiss committee have also recommended this frequency as a standard. One of the reasons why Switzerland has adopted a 15 cycle standard with a 10 per cent latitude up and down is that the existing hydroelectric works have generally frequencies between 40 and 50 and by installing a frequency transformer of 3 to 1 ratio they could utilize their spare power for railway supply. As both Switzerland and Italy are water power countries and as the capital outlay for hydroelectric works is much heavier than for steam driven stations it is a matter of great economic importance to utilize the existing plants to the fullest possible extent and for this reason it seems unlikely that the standard of 15 will be abandoned for one of 25.

As regards pressure we have in Europe also a great variety, including all voltages from 2,000 up to 20,000, but the tendency of new lines is to adopt a pressure in the neighborhood of 10,000 volts. This is not so very different from Mr. Murray's suggestion that one need abandon the idea of coming to an understanding. Mr. Murray has shown that a pressure of 11,000 volts can be safely employed and there is nothing to prevent this standard being adopted also in Europe.

As regards the design of motors the question whether the frequency shall be 15 or 25 is not of paramount importance. Mr. Eichberg (whose motors are made by the Allgemeine) favors 25, while other firms, notably Siemens-Schuckert, favor 15, but there is no scientific reason which should make it impossible to design any type of motor for either frequency. As Mr. Murray has shown by his practical success that the frequency of 25 is possible there does not seem to be any very pressing reason to abandon it. The argument that some types of motor can be built a little more conveniently for the lower frequency can hardly be considered to weigh very heavily in comparison with the practical success which has been achieved with the higher frequency.

DISCUSSION AT TORONTO

N. W. Storer: As Mr. Murray has kindly omitted all reference in his remarks to the locomotive I will make a few remarks about it.

You may think that the greatest point of difficulty in connection with the electrical locomotive today is with the electrical features of it, that is, the design of motors and control, but it may be questioned whether that is absolutely true. There is no question about it that the electrical features have required most careful designing. But I believe the one point that is attracting as much attention from our locomotive designers at the present time as any other, is the method of connecting the motors to the drive wheels. Now, what is the best connection for transmitting the power? We have in the New York Central locomotive probably the simplest. There the field of the motor is made a part of the frame of the locomotive. The armature is pressed on the axle. That has some difficulties in the way of additional dead weight on the axle, which some people claim has been very detrimental to the road bed. At any rate when we discussed with our good friend Mr. McHenry the design of new locomotives, there was one specification which he absolutely insisted on, there must be no dead weight on the axles excepting the axles themselves and the wheels; the motors must be spring supported. That specification has been maintained, and I must say I am in absolute accord with his views on the matter, that there should not be unnecessary dead weight on the axles.

The design of the original locomotive was also limited by the insistence on having no gears. That I believe was a very good thing. I think we have made a greater success of the proposition than we should have done at that time with gears. The motors have been mounted on quills. As probably most of you are familiar with the design I will not attempt to explain it in detail, but the motor is concentric with the axle and drives the wheels through springs. Now, the later forms of locomotives have a gear reduction. This 071 as it is familiarly known has the motors arranged directly above the axle and they are geared down to the quills; the springs connecting the quills with the wheels are long and quite flexible, so that there is sufficient play there to permit the motor to be mounted rigidly on the frame of the locomotive and to move with it, allowing an inch and a half of play either above or below the normal position. That is the easiest riding locomotive I was ever on and I believe I have ridden on practically all of the different types of electric locomotives in the world at this time. Without any question it is the easiest; that is, as far as the comfort of a man in the cab is concerned, and I believe ease on the road-bed as well.

Another type of drive which is now being used to some extent in this country and a great deal abroad is the side rod type. That is a reversion to the old steam locomotive practice. We found that some railroad people were never going to be satisfied until they had side rods on their locomotives. Without them the thing didn't look like a locomotive. Mr. Murray even criticized our first design of locomotive because he said it didn't have any distinctive appearance about it, it didn't look like a locomotive.

Now, this side rod type has been applied on the Pennsylvania electrification at the New York terminal and it is doing very good work indeed. Those locomotives are probably more powerful than any other in the world. They will pull an 800-ton train up a two per cent grade at 30 to 40 miles an hour; they will start the train equally well. That means a good deal when you consider there are only about 100 tons on the drivers and it requires 60 to 70 thousand pounds draw bar pull to do that.

We have been extremely fortunate and I want to say the whole railway world owes Mr. E. H. McHenry, the Vice-President of the New York, New Haven and Hartford, a debt of gratitude. He has been perfectly free to accept the responsibility and to afford all of the contractors the greatest latitude in working out designs, to afford them the opportunity to try new devices and new designs which appeared to have merit. At this time there are orders placed and locomotives practically completed of several different designs, or rather modifications of one or two designs, they are more samples. They have that 071 type which was built as a sample but was found so good that they built the Hoosac Tunnel locomotives identical with it, mechanically and electrically, except that they are straight alternating current instead of alternating current-direct current. They have now a side rod locomotive. 070 has two very large motors driving through side rods similar to the Pennsylvania locomotives. There is in the shop a switcher locomotive which is illustrated in the paper which has the four motors above the axles geared down to quills.

There is the 072 similar to the 071, but with some modifications as found desirable and possible after the experience of building one.

Then there is another locomotive which I feel is going to be one of the best that we have yet been able to produce and that will be known as 069. It is going to be an " earlier " type but it is not quite finished yet. It looks at first thought as if it might be a mistake, as if somebody's slide rule had slipped a little bit, but I don't think that is the case. We have eight motors on that locomotive instead of two which the side rod locomotive takes. We have two motors for each driving axle. The motors are mounted in pairs and geared directly to the quills. We use two motors to replace the one large one. The reason for that is plain, when you consider the matter. The space between the wheels on a locomotive is very limited and when you come to build large motors you find that a very large portion of that space must be used in gears. For instance the large motors on that 071 have two gears of 4¾-in. face each, so that there are 9½ in. gear space; add to that the space required for gear cases and you find you haven't very much space left for the motor. That means that the motor must be made very large in diameter in order to get the torque, which runs up the peripheral speed of the armature and cuts down the output in that way. The smaller motors have been well and thoroughly developed for car uses and they do not require as large a gear. By mounting two of these motors together we can connect them both to one large gear of very much narrower face than the sum of the two gears on the large motor, so that we are able to utilize this space much more efficiently between the wheels than would be possible with a large motor, and we find there is a very material reduction in the weight made possible by that arrangement.

That is, however, not the only new feature about this locomotive. The running gear is quite different. It has four pairs of drivers. There are two middle drivers which are mounted in the rigid frame that the cab is mounted on; instead of having two six wheel trucks as this 071 has there are four drive wheels in the middle of the locomotive, and at each end there is one driving axle and a pony which are mounted in a truck by themselves and swing more like a Mallet locomotive. It has something like a Mallet hinge in there; it is a modification of that idea, but it results in a very light flexible locomotive which I think is going to be a winner. The control instead of being complicated by the number of motors is very much simplified and reduced in weight as well, so everything tends to make that an extremely light locomotive, one that you are going to hear from shortly.

You would be surprised at the interest that is being taken all over Europe and this continent as well on the subject of electrification. In South America they are working on it; they have a number of large propositions and are quite wide awake in Chili, Peru, Brazil and in the Argentine. They are doing wonderful things down there. In Europe they are very much alive to the subject, and with the exception of the Italian State railways all countries have adopted single phase as the medium for the electrification of railways. So that we are not alone in this country in advocating that system. It is the standard which has been selected after great thought and study by the Germans, the Swiss, the French and the Swedes and it has been introduced in England. I received a paper a couple of weeks ago which follows exactly the same line with Mr. Murray's. It is written by Philip Dawson. He is a prominent engineer in London who has superintended the electrification of the branch of the London, Brighton & South Coast Railway there. That is a line at present only about nine miles in length, almost within the limits of the City of London. They adopted for that the single phase system, in spite of the most tremendous opposition among engineers there which has been practically of the same nature as in this country. They adopted it and after several years, for things move very slowly in the old country, they put it in service about a year and a half ago, and I had the great pleasure of going over the line with Mr. Dawson last spring, and he explained to me how well they were operating, and I could see from the results they were getting that everything was running in splendid shape. The work was not pushed as fast as it was on the New Haven road and they had the advantage of the experience of other roads which had been operated before they started out, so that I don't think they have had as many interruptions and as much grief as we had on the New Haven road. But they are getting splendid results and Mr. Dawson's paper is a strong endorsement of the system. The result is just the same as it is in New Haven. They are going to extend it; they are going to extend it right away, and they have voted the money for that purpose. It is a very noteworthy point, that single phase railways are as a rule extending their lines, but it is not very often the case with the direct current lines; when it comes to the electrification of steam railways they hold on a long time before they extend them beyond the limitations which are required by law. The B. & O. Railway electrified its tunnel at Baltimore ten or fifteen years ago and it has the same length of electrification today as it did then. It is a success as far as it goes. The New York Central electrified at the same time that the New Haven did, or somewhat before, but we don't hear any talk of their extending their electrification, but the New Haven electrified with the single phase system is pushing right ahead. They have a system which is flexible and it will admit of the greatest degree of extension. The London, Brighton & South Coast in England is the same way; they can expand and extend their lines.

I have been making a few calculations lately about the loss in power. On a direct current system or any system, with 1,500 volts on the line, with a line say 20 miles long, with two Number 0000 wires for overhead conductors, with a station at each end of that 20 mile line, you run a single car over that line at schedule speed of about 40 miles an hour and you will lose five per cent of your energy in the line. That is with a line only 20 miles long with a sub-station at each end and about 1,500 volts on the line, and only one car. If you run two cars in one train it will double your percentage of loss. Take a single phase system with 11,000 volts on the line, a 40 mile line feeding from one end only, and your average loss in that line with a car going over it will probably not be more than one half what it would be with the single car on the 20 mile stretch.

Single phase equipment is unquestionably heavy; it is heavier than the direct current or three-phase equipment. For that reason it requires more power to carry the car over the line, but when you consider the loss in the line between the car and the substation you will find it is on the other side of the ledger before you get past the substation. There is more power required for the low voltage system. You have got to have high voltage in order to make electrification a financial success.

B. G. Lamme: Mr. Storer has already discussed the locomotive very fully and therefore I will confine my remarks to certain general features of the system, which Mr. Murray has mentioned, but has not emphasized as fully as might be.

Take, for instance, the original system proposed for the New Haven Railway. It was planned to use high voltage directly from the generator, 11,000 volts at 25 cycles feeding directly into the overhead line. One terminal of the generator was to be permanently grounded. This meant that the supply system contemplated an 11,000 volt generating plant with one terminal permanently grounded, connected without transformers to a trolley system comprising over 100 miles of 11,000 volt overhead line. This was a new and untested condition. A further feature contemplated in this system was that it had to be capable of almost unlimited expansion without undue loss or excessive complication.

The locomotive was also a new type of apparatus, but designed along the lines laid out originally for the single-phase system, in which single-phase commutator motors with voltage control were to be used. By this control the speed of the locomotive was to be varied over any range from zero to maximum speed, simply by varying the voltage supplied to the motors by means of a step-down transformer on the locomotive itself. At the same time the locomotive was designed to operate on 600 volts direct current as well as on 11,000 volts, 25 cycles alternating current.

This New Haven system was installed along the above lines and has been carried through to an entirely successful operating condition and, while certain minor changes have been made, it will be almost impossible for an electrical layman, as you might call him, to find these changes. I mean by this, that if he had looked over the system rather completely in the first place and would look over the present system and equipment, it would be difficult for him to see any differences or changes which would appeal to him as being of any controlling importance. However, a number of changes from the original installation have been made, and I wish to call attention to the fact that these changes have consisted almost entirely of *additions* to the system and equipment to meet unknown or new conditions which have developed since the system was first installed, that is, these changes have not been made to correct what might be called mistakes or errors in the original layout. Also, a number of the modifications may have been in the nature of developments which will find application in other fields besides single-phase railway work. Take, for example, the generating plant. In order to adapt very large capacity generators for single-phase railway operation, new problems were encountered which had not proven serious in small size machines. For instance, complete cage dampers were put on the rotors of the generators to repress the pulsations due to the single-phase armature reaction. Since these machines were installed it has become a recognized practice in all very large high-speed single-phase generators to equip the rotors with some sort of cage dampers. Such generators are coming into use for other purposes besides railway work, electrochemical work and electrofusion being examples.

Take another feature of the generating plant, namely, the addition of choke coils in the leads between the generator and the overhead system, as was described in connection with Mr. Murray's former paper before the American Institute in December 1909. These choke coils were added for the purpose of reducing the enormous current rushes which occurred in the case of short circuit on the line. This practice of using choke coils for the protection of large turbo-generators is now being applied in a number of cases in connection with three-phase high voltage machines. The application of this principle which is used in the New Haven single-phase plant is now being carried into other fields than single-phase railway work.

Take another feature, namely, the selective system which is developed in connection with the New Haven overhead system. In this system, in case of a short circuit, a resistance was introduced to take up the load before opening the circuit. The object was to avoid suddenly opening an enormous inductive load, with consequent possible disturbances on the generators and system. In order to open the circuit the inductive load was first transformed to an energy load by means of the introduction of resistance, and then this energy load, of considerably reduced amount, was opened by the breakers. This arrangement contains the germ of a practice which may eventually be carried into the whole field of transmission work.

Considering the transmission line, the use of the steel trolley wire below the main wire may be regarded as an addition pure and simple, and a very helpful addition from a mechanical standpoint. The original copper trolley wire served two purposes, namely, as a feeder or conductor, and as a contact wire for supplying current to the locomotive. The addition of the steel wire takes away from the copper wire its function of a contact wire, but it still serves its function as a conductor. The copper wire could not be taken out and the steel put in place of it, as the low resistance of the copper conductor is needed. Therefore, the copper still serves its more important function and the steel wire placed beneath it takes care of the mechanical requirements.

In the locomotives a few changes have been made since the original installation but they have been of a comparatively minor nature. The principal changes have been in the nature of additions rather than modifications. For example, part of the control system was increased in carrying capacity on account of the fact that the motor capacity actually proved greater, by about 15 per cent, than originally expected. The change in the control to take advantage of this increased capacity cannot be charged to a mistake or error, but should be credited as an improvement to obtain increased capacity. The original guaranteed continuous capacity of the locomotive motors was about 830 amperes. Some of these motors, on actual test, showed a continuous rating of approximately 1,000 amperes. This increase in capacity over what was proposed can now be taken advantage of in the operation of the system.

In connection with the original overhead system there was considerable talk about the possible large line drop. In practice, that question has not troubled anyone. A more serious trouble has been that the line drop has been very small, so that in case of short circuit anywhere on the line, enormous current rushes would occur which were destruction to the system. These were later taken care of by the choke coils and the selective system, as mentioned before. This low line drop, however, is just what is required if extensions are to be made in this system. Mr. Murray now announces that the present overhead system is to be continued down into the Harlem Yards, and his figures indicate that even with the enormous extension which is contemplated the maximum line drop will still be comparatively small.

Taking this system as a whole, it may be noted that the original voltage of 11,000 has been maintained; also, the original frequency of 25 cycles. No transformers had been added and the system can be extended as originally intended. The fact that the 100 miles of overhead work is now being increased to 500 miles without transformers shows the flexibility of the system. In all the history of electrical engineering I do not know of any undertaking which had as many new and untried features as this system has, which has been carried through to success with as close adherence to the original lines.

There is one feature in connection with the generating plant which has not had its full significance brought out before. I refer to the use of 11,000 volt machines with one terminal grounded. These generators have three-phase armature windings of the star type with one of the three terminals permanently grounded. Two of the legs of the star are used for the single-phase circuit, while the third leg is used in connection with certain three-phase work. Across the railway phase the potential is regulated for 11,000 volts normal, by means of an automatic regulator in connection with the fields of the generator. The third leg gives a little higher voltage normally, due to the small load which it carries at present. In consequence, its voltage is usually somewhere between 11,000 and 12,000 volts. Assuming this at 11,000 volts, then in these machines we have an equivalent, as far as insulation stresses go, of a three-phase generator with grounded neutral *with* 11,000 *volts between the neutral and the terminals*. This therefore is practically the equivalent of *a* 19,000 *volt three-phase generator with the neutral grounded*. It is more than this, as it is the equivalent of a 19,000 volt machine with the neutral grounded and *with the terminals tied directly to* 100 *miles of* 11,000 *volt overhead system without the interposition of transformers*. This is a very abnormal condition compared with anything that is being done in this country at present. 16,500 volts is the highest generator now used on a large scale, as far as I know. But here we are actually running under conditions corresponding to

19,000 volts with the hardest kind of service and with an overhead line without transformers which is going to be extended to about 500 miles. Under these conditions the generating plant has made an extremely good record, as indicated by Mr. Murray in his table of delays due to power house. I may say that for about two years, or possibly more, there has been practically no trouble as far as the generators are concerned; that is, any trouble which would shut down the system. There has been one breakdown in one machine, but a careful examination of this one case developed no cause for the breakdown other than a damage to the insulation in originally putting the coil on the machine. There were no signs of deterioration of the insulation, and the insulating materials on the damaged coil appeared to be as sound and flexible as when first put on. So here we are running machines at the equivalent of 19,000 volts on a three-phase system, and during two years there has been continuous service. This is a most excellent record. If we compare this with a late practice, now being advocated here and there, of winding large turbo generators for low voltage, such as 2,200 volts, and then stepping up to voltages, even as low as 6,600 volts, we can see what a wonderful thing this New Haven operation is. In some cases at the present time, 11,000 volts, or even 6,600 volts on the generator, is being condemned as bad practice because of dangers from line voltage, surges, lightning and such things, but in this New Haven plant there are 100 miles of overhead system under conditions where it is exposed to surges of the worst sort.

Referring again to the locomotives, the motors were popularly considered as the questionable feature of the whole system. Of the first type of locomotive, 41 were built, all of the gearless type with four motors each. The motors furnished, which were 250 to 300 h.p. were by far the largest up to that time. These motors were supplied with the so-called resistance leads which were considered by many to be a very harmful feature and a source of great loss. These locomotives have been in operation between three and four years and as far as we have had an opportunity to examine the resistance leads on the armatures of these locomotives they have shown no signs of over-heating or undue loss. In fact, in one case which I examined personally the copper winding showed more evidence of heating than the resistance leads. It should be borne in mind also that at times these motors have been very heavily overloaded. The record as a whole may be considered as good as that of corresponding direct current motors.

One very good feature has developed in these single-phase locomotive motors, namely, they are able to commutate well over an extremely wide range of speed. In the ordinary direct current motor of the non-interpole type, the commutating conditions become perceptibly worse as the motor speed is increased when carrying a large current. On the single-phase motor this condition is not encountered to the same extent. The short circuit current in the resistance leads decreases as the speed is increased so that the reduction in such current with higher speed compensates, to a considerable extent, for the effect of the increase in speed, so that the commutation as a whole seems to be equally good from very low speed up to very high speeds. This is of particular advantage in a system where voltage control is used, for it allows us to push up the voltage applied to the motors whenever there is occasion to do so.

Mr. Murray mentioned a new locomotive of the side-rod type, with two large motors. These motors are of nominally 600 h.p. continuous rating at about 200 revolutions at normal voltage. Claims have been made from time to time that with 25 cycles it was not possible nor practicable to build single-phase motors of more than 200 or 300 h.p. continuous rating, but tests on these 600 h.p-motors indicate that they work just as well as motors of 100 h.p., for instance. These motors have been loaded up to 100 per cent overload current and they commutate just as well as smaller ones.

In conclusion, I will say that the single-phase system in this country has its greatest example in the New Haven electrification. There are also a number of smaller systems which use single-phase railway motors, such as the Spokane & Inland Railway in the far West, and the Sarnia Tunnel near Detroit, which uses single-phase electric locomotives entirely. In Europe they have not put the single-phase system into commercial use on as large scale as in America, but in a number of European countries the single-phase system already has been adopted as standard for heavy railway work, and they are expecting to install the system on a comparatively heavy scale in the near future. Although the experience in Europe with this system is as yet more limited than in this country, yet it has satisfied them that the system can be adopted for main railway electrification.

W. S. Murray: With the exception of Messrs. Sprague and Katte, those who have contributed to the discussion—both on the American and European side—seem to be in general agreement with the author, but for a few exceptions with reference to details of the system. The author is left, after reading the discussion, with the impression that single-phase power is correctly used when applied to trunk line roads inclusive of terminal, suburban and yard rails. The opening paragraph of the paper advocates this application, and it is most gratifying to find the general support of this recommendation.

Mr. Sprague implies that I said that the time has come when the electrical engineer can say that there is but one system of electrification to meet all the varied problems of railroading. Nowhere in the paper is such a statement made, nor one that could be interpreted to involve such a conclusion. It should be remembered that street railways and trunk lines are two entirely different propositions. In answer to the criticism that no mention of costs is made in the paper I call attention to that part of my paper devoted to electrification costs and under this is discussed power house, line and locomotive costs, and with the closing remarks that "not until the electrical system of the New Haven Road is a unit in itself, rather than a mixed service of steam and electricity, can its true economies of electrical traction be discussed". An extension to New Haven will give this, though even then the highest economies of the single-phase system cannot be realized, due to the necessity of a large portion of locomotives and multiple unit equipment being required to do dual service on alternating-current and direct-current lines. As the electrification only covers 1/5 of the zone ultimately to be included it is not expected that information as to operating costs would be of great value. It does not advance the application of electricity to railroads to proclaim the disappointment at not receiving data which is practically unavailable to the railroad company itself.

Mr. Sprague summarizes the railway system advocated in the paper by the following characteristics:

1. "Single phase transmission at a potential limited by the requirements of the trolley wire from central stations equipped with generators built with variable voltages and operated with grounded circuits".

2. "The abolition of the step-up and step-down transformers."

3. "A potential of 11,000 volts or higher on a trolley line in contiguous territories, but with entire freedom to change that voltage to something different on remote lines."

4. "The abolition of the single-phase 25 cycle motor and the substitution therefore, as a possibility in the near or the dim future, of a single phase induction motor, or in lieu of that the much criticized direct-current motor supplied by a mercury rectifier or its equivalent."

Commenting on these characteristics it should be noted in connection with (1) that variable voltage generators were not included. The New Haven road has used and intends to use only constant potential generators unless later conditions require otherwise. With reference to (2), the system described does not rule out the step-up or step-down transformer. We are contemplating using some shortly but the distances of our transmissions to date are short enough to be economical without them.

With reference to (3) Mr. Sprague states the situation correctly.

With reference to (4). It is common knowledge that the cost of power stations of the single-phase or three-phase type may be equated. It is common knowledge that single phase propulsion equipment is more costly than direct-current equipment; *but it is also common knowledge among those who have had practical experience with the accounts incident to alternating-current and direct-current operation that it is in the distribution system that the economy of single-phase traction lies.*

Having admitted that direct-current propulsion equipment is less costly than alternating-current, and notwithstanding this fact that the ***single-phase system*** is more economical than the ***direct-current system***, why, if 25 cycles is the frequency more conducive toward a reduction in propulsion apparatus cost for the reasons mentioned in the paper, should it not be advocated?

Thus I believe that the discussion has wandered from the particular points and system described in my original paper.

Mr. Katte criticises the absence from my paper of figures for relative costs per ton mile of steam and electric trains in similar services. Yet in the same paragraph of his discussion says " Here I may add that cost figures for comparative performances on the N. Y. C. system are not available for the reason that the service is still mixed steam and electric ", thus ignoring the fact that the same difficulty exists on the New Haven. There is in addition the complication due to the operation with both single-phase and direct current.

In connection with the subject of train delays which is brought out in Mr. Katte's tables due consideration should be given to the relative ages of the two systems employed. It is not remiss to mention here that of all the roads entering New York City, the New Haven had last year the record of handling the highest percentage of trains on time.

Mr. Katte claims a higher efficiency for the New York Central locomotives than for the New Haven. He states that trains of similar weight are handled by the New York Central at an average energy consumption of 23 watt-hr. per ton mile whereas he gives figures for the alternating-current run between Woodlawn and Stamford on the New Haven of 32.5 watt-hr. per ton mile. I do not know where the figure for the New Haven services was obtained but I deny that for equal conditions of load and service the New Haven ***takes 42 per cent more power than the New York Central.***

My own calculations are based on the fact that it is conceded that the alternating-current motor has a range of efficiency 2 per cent below that of the direct-current motor. The published curves of the New Haven and New York Central locomotives show this. Under the condition named the watt-hours per ton mile are a straight function of the locomotive efficiency, which means a difference of 2 per cent as against 42 per cent. Moreover, carrying these calculations back to the power house the fact should be borne in mind that a 15 per cent saving in transmission losses offsets the loss in the motor over six times. The cost of the actual coal burning is proportional to the energy generated at the power station and not to that consumed by the locomotives.

I wish to take this opportunity of thanking Messrs. Fritch, Woodbury, Jackson, Storer, Lieb, Scott, Dawson, Smith, Taylor, Lamme, Graftio, Kapp and Steinmetz for their liberal discussion of the paper. I find myself with the feeling, after reading their contribution to the discussion, that in the specific matter of what type of electrification should be applied to trunk line rails inclusive of terminal, suburban and yard service, that if not entirely individually sustaining, their general conclusion sustains the author's point of view. Some of these gentlemen have differed with the author, and quite decidedly in points of detail, and for this difference of opinion I of course hold only the highest respect and acknowledge the valuable information presented.

Briefly commenting on the discussion of the gentlemen above referred to, it is extremely gratifying to find Mr. Fritch in agreement with my recommendations as to standardization. He epitomizes the situation in saying: "As long as the system is not established you are simply furnishing ammunition for those who do not desire to electrify." Particularly pertinent do I consider Mr. Fritch's remarks with reference to the electrification of yards. By the use of the overhead system the problems of readjustment of obstacle and equipment clearances, the disbarment of certain classes of rolling stock and the general complication and awkwardness incident to a ground conductor are eliminated and the yards and terminals can be treated, in so far as ground conditions are concerned, in a manner exactly as in the past. It is common knowledge that in yards the least amount of money possible is spent on track and ballast—two items in intimate difficult relationship with reference to the adjustment of the ground conductor (third rail) whose location is a matter of the fraction of an inch, while in the case of the overhead wire its unit of adjustment is the foot. The simplicity of the overhead construction and its susceptibility to a standardization for all railroads is easily apparent.

I have read with a great deal of interest and instruction Mr. Woodbridge's discussion with reference to the matter of storage batteries for trunk lines, and I am interested to note that he believes there are places where the battery would be of economic value. It is due Mr. Woodbridge for me to say that I had the specific cases of the New Haven and the New York Central electrifications in mind. In the case of the former it would have been quite uneconomical, and having conferred with the New York Central engineers about the installations of the batteries upon their lines, I was advised that had they to do it over they would not be installed, and in their contemplated extensions no batteries would be installed. It might be well to say here also that both the New Haven and the New York Central roads are of a class typical (in the heavier form) of trunk lines I have had in mind in connection with recommendations made in the paper.

With reference to the closing paragraph of Mr. Smith's discussion, which seems to epitomize what has preceded it, I would say I am heartily in agreement with Mr. Smith that the future may develop some method less costly both as to investment and daily operation than the system now employed by the New Haven road for the electrical operation of its trains. I should indeed be greatly disappointed if what we have today is not greatly improved upon in the future. Let us, however, while hoping for better things, not hesitate to go ahead with the foundations already laid. Because we may believe what we have is the correct underlying principle and advance it in every way in the field of practical application, cannot possibly dim the chances of some better system of the future to take its place.

I feel that the underlying principles of the single-phase system have been sufficiently exposed to ratify its post, and to build on them in the future. In my opinion it will be more costly to wait than to go ahead. It cannot be denied that a universal standard of trunk line electrification would be most acceptable to all railroads. With the exception of a very few engineers, we hear it said that all three systems will work—the direct current, three-phase and single-phase. If this is so, then let us elect one and apply it to trunk lines to be electrified, and I believe we have enough data to date to show that the single-phase for this class of electrification has inherent in it the economic factors necessary to its selection as the standard. It seems to me the time is at hand, or very nearly, when we must select and not enumerate. There is a limit to the capacity of any ship. If she has to carry much more discussion she may sink.

I am very glad to have Dr. Steinmetz' agreement with reference to frequency. The reasons he has presented, together with those mentioned in the paper in connection with the possible future introduction of the induction or direct-current motor, still using the single phase system of distribution, would seem to be entirely consistent.

I think Mr. Taylor has brought out a good point of information, with reference to the difference between phase and voltage balance, and while what he says is quite true, I do not see that it makes necessary any change in the quotation he has cited from the paper.

With reference to Mr. Lamme's and Mr. Storer's discussion, I can only express my thanks for the interesting points brought out with reference to the generator and locomotive features of the system; the developments in these departments being due almost entirely to the patience, pluck and ingenuity of these gentlemen.

With reference to Mr. Graftio's discussion, I cannot see how his " Queen " (the steam locomotive) can be used as a reason against a choice of system for standardization. His " Queen " includes in it all the variable (speed and torque) characteristics that have unified steam standardization, and they can be all duplicated in single-phase locomotives.

Mr. Kapp's conclusion with reference to standardization is most encouraging. It is interesting to note that in Europe there is a strong trend to standardize and it is most gratifying to know that for trunk lines the type of electrification has practically been settled upon in favor of single-phase.

The paper was presented to give up to those who have responsibilities, or to whom later responsibility for electrification of steam road bed may come, information that to the date of the paper had been collecting in my files. Minute costs relating to investment and operation, due to the incomplete state of electric engine stage (division run) was avoided and this feature of electrification was touched upon only in the most general way. The now acknowledged and indisputable principles of economy inherent to the single-phase system as applied to the trunk line system is the guarantor of the results that may be reasonably expected when a sufficient time has passed to stretch its length into an engine stage.

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AUTOMATIC MOTOR CONTROL FOR DIRECT CURRENT MOTORS

BY ARTHUR C. EASTWOOD

" The flexibility of the electric motor " is a well worn phrase and one which is quite commonly accepted at its face value. As a matter of fact an electric motor has quite definite characteristics, and these characteristics usually must be modified by some form of controller to adapt a given motor to varying conditions.

At the present time there is probably no branch of industry in which a machine is used which has not been invaded by the electric motor. This general use of electric motors carries with it the fact that these motors are daily started and controlled by al classes of operators, from the most highly skilled to the most ignorant and careless.

Where a manually operated starter is used, the rapidity with which the starting resistance is cut out, and hence the accelerating current, is left to the judgment of the operator. If the operator be ignorant or careless, damage to the motor and to the driven machine may result from cutting out the starting resistance too rapidly. On the other hand, if he is over-cautious he may consume more than the necessary period in cutting out the starting resistance, causing a waste of time, and possibly also a burned out rheostat. Or, if an operator be transferred from a machine which has small inertia and starts easily to a machine or tool which has great inertia (such as a punch press having a heavy flywheel), if he has not been previously instructed in the starting of the heavy machine, this part of his education may prove expensive to his employer.

Where motors are to be reversed as well as simply started, the possibility of damage to the motor and driven machinery, due to careless manipulation of the controller, is much greater than is the case in simple starting because, if the motor connections be suddenly reversed while the motor is running, the counter e.m.f. of the armature becomes additive to the line voltage until such time as the armature has been brought to rest. In the case of series wound motors running under light load or of shunt wound motors running with weakened field, the voltage impressed on the armature and the starting resistance may readily be several times the normal line voltage. Destructive currents may therefore occur if the resistance is cut out too rapidly in the reverse direction.

Obviously the ideal arrangement for starting or reversing a motor is a starter or controller which will " do the thinking for the operator ", leaving it to him to simply push a lever to start the motor and pull the lever to stop the motor.

In the case of any motor-driven machine or tool there is a maximum safe accelerating current which should not be exceeded. This maximum safe current may be determined by the ability of the motor to commutate properly, or it may be determined by other conditions such as the slipping point of belts in a belt drive.

The ideal starter or controller should be so arranged that this maximum safe current cannot be exceeded. It should also be so arranged, in the interests of efficiency both as to current and to time, that the current during acceleration will be kept as closely as practicable up to the safe maximum value. In other words, the starter must automatically interpret load conditions. If the load be light the starter must see to it that the motor is brought up to speed quickly, while if the load be heavy, the period of acceleration must be correspondingly longer.

In the past there have been several types of starters and controllers which have approximated the characteristics above detailed. First may be mentioned the " time element " type in which the starting resistance is always cut out in a fixed period of time. This type of starter falls short of the ideal in that it cannot adapt itself automatically to variation in load.

Second, the " counter e.m.f. " type in which the starting resistance is cut out by a magnet or magnets which respond to the counter e.m.f. of the motor. This type of starter or controller has done good work in elevator service but is open to the objection that its action is disturbed by fluctuation in line voltage.

Third, the " current limit " type in which the cutting out of the starting resistance is governed by the motor current. This type is generally characterized by a number of shunt-wound magnetically-operated switches which control the starting resistance and one or more series relays which respond to the motor current and serve to check the successive closure of the resistance switches when the accelerating current exceeds a predetermined maximum. This type, which I will call the " shunt current limit type " in order to distinguish it from another type to be later considered, approaches the ideal very closely and has been the direct means of introducing the electric motor in many applications where steam and hydraulic power had been the previous standard.

A specific instance in point is found in the introduction of the motor drive for " reversing mill tables " in steel mills. These tables are reversed several thousand times a day, and up to less than ten years ago small steam engines were universally used to drive them. It had been attempted to use motors for the purpose, but with manually operated controllers and operators accustomed to operate hydraulic or steam valves both the motors and the machinery were so severely punished by excessive currents, due to cutting out the starting resistance too rapidly at the time of reversal, that the arrangement was operative, in a practical sense, only in the hands of a skilled and careful operator, and was too delicate to be used as standard equipment in a steel mill. The advent of the automatic magnetic controller, which automatically keeps the acceleration current within fixed limits, overcame the difficulty. With this type of control the master controller can be operated as rapidly and roughly as a hydraulic valve with no danger to the motor or the driven machine. No particular skill is required of the operator in starting or reversing the motor. It is left to him to simply push a lever to start the motor and pull a lever to reverse the motor. He is therefore free to devote all of his attention and skill to the business of working steel. He is no longer a combined motorman and steel-worker but a steel-worker pure and simple.

In addition to this advantage of the automatic controller, in that it eliminates the necessity for skill on the part of its operator, it carried with it other advantages having a direct bearing on increase in output. Among these advantages may be mentioned the following:

1. The master-controller is small and easily operated. The

physical endurance of the operator is eliminated as a factor in the output of the mill.

2. By keeping the accelerating current as nearly as practicable up to a safe maximum the motor is always brought up to speed in minimum time.

3. By keeping the current at the instant of reversal within safe limits delays due to both electrical and mechanical breakdowns are greatly reduced.

With these very practical advantages demonstrated, the electric motor with automatic control was very promptly adopted for the drive of mill tables, and is now the accepted standard in steel mills for this and many other drives.

The ***shunt type of current limit controller*** accomplishes the results for which it is intended in a thoroughly practical and satisfactory manner, but its general use is precluded at the present time by the fact that it is a highly organized piece of apparatus which is too complicated to be readily understood by an ordinary electrician. In other words, while the shunt type of current limit controller eliminates skill on the part of its operator, it requires a somewhat skilled electrician for its proper maintenance.

Some recent developments in automatic motor control of the current limit type which result in a very material simplification of the controller are described below. This new type of automatic controller or starter is known as the ***series current limit type*** in view of the fact that the magnetic switches which control the acceleration are series wound and their windings are connected in series with the motor to be started or controlled.

This type of controller is made possible by a type of magnetically-operated switch which possesses remarkable characteristics.

This switch acts not only as a switch for closing a circuit and holding it closed, but acts also as a current limit relay or so-called " throttle ". If the current which flows through the winding of the switch is below a certain critical value the switch will close instantly, while if the current is above this critical value the switch will " lock out " or refuse to close till the current has been reduced to the critical value. Means are provided whereby the critical value of current below which the switch will close and above which the switch will lock out may be readily adjusted, thereby adjusting the accelerating current taken by the motor.

Fig. 1 is a cross-sectional view of a typical switch of this type. In this illustration *I* is the operating coil, which as previously mentioned is so wound as to adapt it for connection in series with the motor to be controlled. This winding is carried by a brass tube within which the core *E* is free to reciprocate vertically. The upper end of the core *E* carries a non-magnetic stud to which is attached a copper contact plate *G*, adapted to make contact with a pair of contact brushes *H* when the switch is closed. The lower end of the core *E* is reduced in cross-section and forms a stem *F* which meets the body of the core to form a shoulder. The stem *F* passes into a hollow adjustable plug *C* which is of magnetic material. The winding of the switch is enclosed and protected by a semi-cylindrical iron casing *A* which also constitutes the return member of the magnetic circuit. The upper member of the frame or case *A* is provided

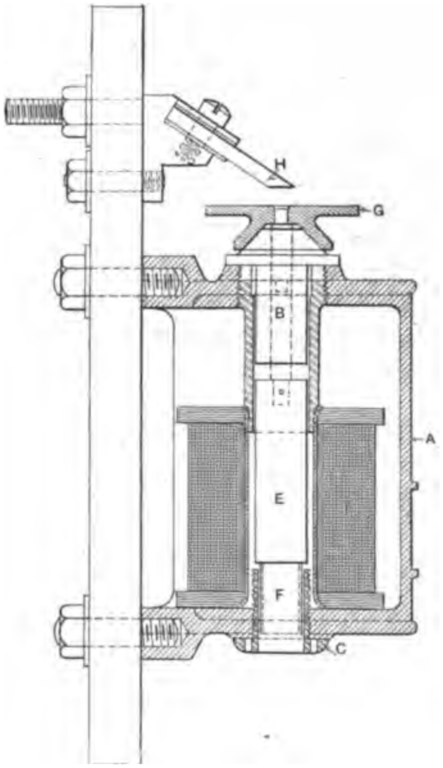


Fig. 1

with a plug or pole piece *B* of magnetic material. When current flows through the winding *I* magnetic flux passes between the plug *B* and the upper face of the core *E*. Substantially all of this flux is normal to the face of the core *E* and is effective in producing a magnetic pull tending to close the switch. At the lower end of the core, however, the flux has two paths. One of these paths is from the horizontal portion of the frame *A* into the sleeve or hollow plug *C*, and from the upper face of this sleeve through an air gap into the shoulder on the core. This portion of the flux takes a direction practically normal to the face of the shoulder on the core and produces a magnetic pull which tends to move the core downward or, in other words, tends to prevent actuation of the switch. Through the second path at the lower end of the core a portion of the flux passes directly into the stem or extension *F* in a direction at right angles to the direction of motion, and this portion of the flux is therefore not effective in producing a pull on the core *E* in a vertical direction. The total flux divides between those two paths inversely as their reluctance. With a small current in the winding *I* substantially all of the flux passes directly into the extension *F*, this path being of much less reluctance than the path including the air gap. The extension *F*, however, is of restricted cross section and as the magnetizing force is increased the reluctance of this path increases and more and more of the flux is crowded into the air gap.

The core *E* is then acted upon by two forces—one the magnetic pull at its upper end which tends to close the switch, and the other made up of the weight of the moving parts plus the downward magnetic pull at the shoulder on the plunger. When the current is below a certain critical value the upward pull is greater than the downward pull plus the weight of the moving parts and the switch will close. When the current is above this critical value the downward pull plus the weight of the moving parts predominates and the switch cannot close.

The critical point below which the switch will close and above which it will " lock-out " is adjusted by screwing the adjustable plug *C* in or out which adjusts the lower air gap. This has the effect of altering the reluctance in the path including the air gap with respect to the reluctance of the path including the stem or extension *F*. Screwing in the plug and thereby shortening the air gap has the effect of decreasing the value of current at which the switch will " lock-out ", while increasing the air gap has the effect of increasing the value of current at which the switch will " lock-out ".

Fig. 2 is a reproduction of the operating curves of one of these switches. The ordinates of these curves read in amperes and the abscissas in fractions of an inch, showing the length of the lower air gap.

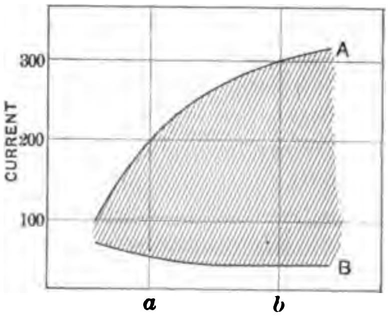


FIG. 2

The upper curve *A* is the " lock-out " curve, and the lower curve *B* shows minimum current at which the switch will close. The switch will close at any value of current between the two curves as measured on an ordinate corresponding to the length of air gap under consideration.

It will be observed that the curve *B* is a substantially horizontal line which shows that the minimum current at which the switch will close is very little affected by altering the lower air gap. The form and general pitch of the operating curve *B* are matters of design into which the diameter of the stem or extension at the lower end of the core relative to the diameter of the core at its upper end and also the location of the magnetizing winding relative to the two air gaps in the magnetic circuit enter as important factors.

FIG. 3

FIG. 4

After the switch has closed it is held closed through a substantially closed magnetic circuit and it will therefore be held closed till the current in its winding has fallen almost to zero. Since both the winding of the switch and also its contacts are in the controlled circuit and the switch will not open till the current has fallen to practically zero, it follows that there can be no arcing at the switch contacts, and hence blow-outs or other arc-rupturing devices are not required.

Figs. 3 and 4 illustrate a complete unit switch of this type in side and front elevation. Starting with this unit switch as a basis, the switch being both a switch and a current-limit relay combined in one mechanism, we will consider some typical combinations of these switches in the form of automatic starters and controllers for performing various functions.

Fig. 5 is a diagram of connections of a simple form of automatic motor starter in connection with a compound wound motor having the armature *A*, series field *F* and shunt field *f*. K is the starting switch which is closed by the operator to start the motor and is opened to stop the motor, this being the only part of the starter with which the operator has anything to do. *S*1, *S*2, and *S*3 are three automatic switches which control the starting resistance *R*. These switches are provided with series-wound actuating coils *C*1, *C*2 and *C*3 respectively. The switch *S*3 is also provided with a shunt-wound holding coil *H*3.

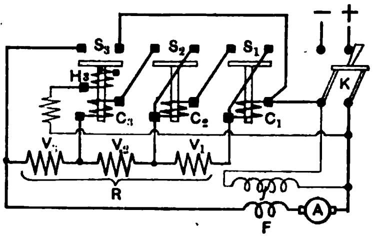


FIG. 5

When the starting switch *K* is closed current flows from the positive side of the switch through the armature and series field of the motor, the entire starting resistance *R* and the actuating winding *C*1 of switch *S*1 to the negative side of switch *K*. The motor should then start, and although the actuating winding of switch *S*1 is energized this switch will not close till the current has dropped to the value for which the switch is adjusted.

When switch *S*1 closes the first section of resistance *V*1 is short-circuited, the path of the current then being from the switch *K* through the armature and series field of the motor, the resistance sections *V*3 and *V*2, the winding *C*2 of switch *S*2, the contacts of switch *S*1 and the winding *C*1 of switch *S*1 to the switch *K*. The winding *C*2 of switch *S*2 is then energized and when the motor current has dropped to the value determined by the adjustment of the switch it will close, thus short-circuiting the section of resistance *V*2. The current then takes the following path: from the switch *K* through the armature and field of the motor, the resistance section *V*3, actuating winding *C*3 of switch *S*3, contacts and winding of switch *S*2, and contacts and winding of switch *S*1 to the switch *K*.

The actuating winding *C*3 of the last accelerating switch is thus energized and when the motor current has dropped to the predetermined accelerating value the switch *S*3 will close. As switch *S*3 closes the circuit through its shunt-wound holding coil *H*3 is completed at the contacts of the switch itself and the switch is held closed by this coil. The closure of switch *S*3 throws the motor across the line through the following path: from the positive side of switch *K*, through the armature and series field of the motor and the contacts of switch *S*3 to the negative line at switch *K*. The contacts of switch *S*3 are therefore the only contacts or connections in the motor circuit when the motor is running.

It will be observed also that closure of switch *S*3 short-circuits all three of the actuating coils *C*1, *C*2, and *C*3. Switches *S*1 and *S*2 therefore drop out, while switch *S*3 is held closed by its holding coil *H*3. It is also to be noted that switch *S*1 in closing closes the circuit through the actuating winding of switch *S*2, while switch *S*2 closes the circuit through the actuating winding of switch *S*3. The switches are thus compelled to close in orderly sequence without recourse to auxiliary or " interlock " contacts.

To stop the motor it is merely necessary to open the switch *K*. In case of failure of voltage the holding coil of switch *S*3 is de-energized and this switch opens, inserting all of the starting resistance *R* in series with the motor. When current is restored to the line (provided the operator has not previously opened the switch *K*) the motor will again be started automatically in the normal way. While Fig. 5 shows the connections for a compound-wound motor, it is evident that the same form of starter is equally applicable to shunt and series-wound motors. In the case of series-wound motors connected to loads which may be so reduced as to cause the motor to speed up dangerously, the starter can be very simply modified to protect against this. To accomplish this the holding coil of switch *S*3 is made a series coil and is connected in series with the contacts of the switch.

Since in a series motor the speed depends upon the current, the holding power of the holding coil will be weakened as the motor speeds up, and the coil may readily be proportioned so as to cause the switch *S*3 to open before a dangerous speed is reached.

A complete starter corresponding to the diagram of Fig. 5 is shown in Fig. 6.

As previously mentioned, there is no danger of arcing at the contacts of the accelerating switches, the motor circuit being initially closed and finally opened at the contacts of the operator's switch *K*. In the case of constantly running shunt or compound wound motors, a simple knife switch or its equivalent is suitable for the purpose where remote control is not a consideration. In applications where short moves of a heavy machine may be made, as, for instance, in setting up the work on a boring mill, provision must be made for the arcing at the operator's switch due to opening the motor circuit when the motor is generating but a small counter e.m.f. This can be taken care of by providing a specially constructed operator's switch having its contacts suitably protected against arcing, or preferably a type of starter illustrated in Figs. 7 and 12 is employed.

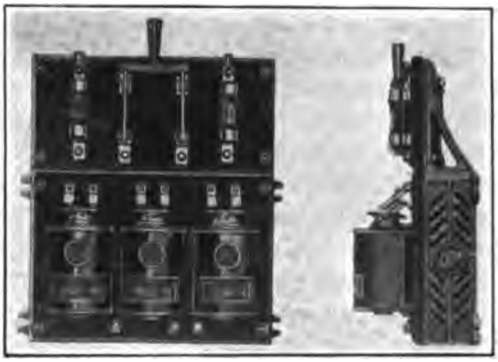


FIG. 6

In this form, in addition to the series-wound accelerating switches, a main switch or initial circuit-closer in the form of a shunt-wound magnetically operated switch or " contactor " is provided. This contactor provides for a quick opening of the circuit in the field of a powerful blow-out magnet such that heavy currents in an inductive circuit are opened promptly and with slight depreciation of contacts.

The use of this shunt-wound main switch makes it possible to use push-buttons or small pilot switches which are used by the operator in starting or stopping the motor. As many of these starting and stopping switches as desired may be placed at convenient points around a large machine or tool, adding much to both the facility and safety of operation. This type of starter is also adapted to remote control by means of a pressure gauge, float switch, or other devices which interpret conditions under which the motor is to be started and stopped. This form of starter is also very simply provided with overload protection, the circuit of the winding of the main switch being broken at the contacts of a small overload relay, as shown in the diagram Fig. 8.

Fig. 7

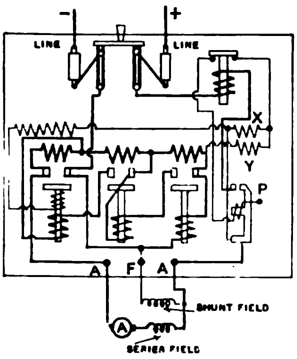


Fig. 8

The minimum number of accelerating switches which may be used in connection with a given motor depends rather upon the amount and character of the load than upon the size of the motor.

In general it may be said that when current limit acceleration is employed relatively very few subdivisions of resistance are required as compared with a manually operated starter. The number of subdivisions of the resistance in a manually operated starter is primarily determined as a matter of protecting the contacts of the starter itself. If too few subdivisions are used the drop between adjacent steps will be too high and serious burning or "bugging" of the contacts will follow.

The automatic starter or controller with current limit acceleration is of course free of this limitation, and in addition possesses the advantage, as far as the motor is concerned, of cutting out successive sections of resistance only when the current in the circuit is at the proper value.

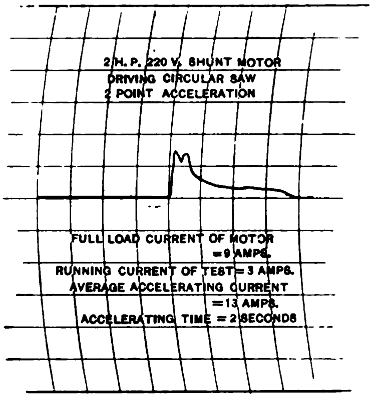


FIG. 9

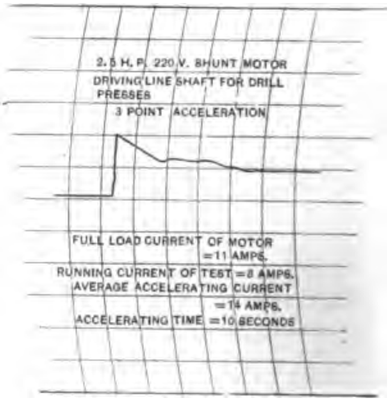


FIG. 10

For motors up to, say, five horse power, starting under light load or starting loads of small inertia, a single accelerating switch is sufficient.

For motors within the same range of horse power, starting at full load or starting loads of high inertia, (such as a machine equipped with a flywheel), two or even three accelerating switches may be required to keep the peaks of the accelerating current within prescribed limits.

Figs. 9, 10 and 11 are reproductions of accelerating current curves taken with a recording ammeter in the circuit of motors equipped with automatic starters of the "series current limit" type under consideration.

Fig. 9 shows the accelerating current curve of a two-h.p.

shunt motor driving a circular saw which starts under very light load. The starter in this case was equipped with but a single accelerating switch.

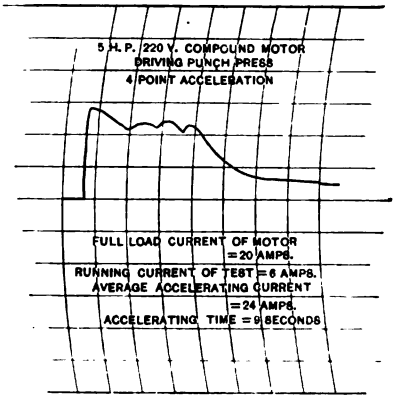
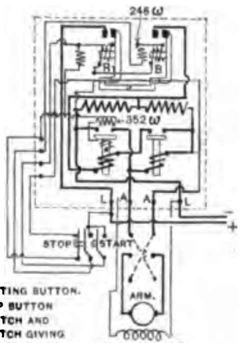


Fig. 11

Fig. 10 shows the accelerating current curve of a 2½ h.p. shunt wound motor driving a line shaft for light drill presses. The starter in this case was equipped with two accelerating switches, giving three points of acceleration including the operator's switch.

Fig. 11 shows the accelerating current curve of a five-h.p. compound wound motor driving a punch press, three accelerating switches being used. In general it may be said that for motors up to 25 h.p. three accelerating switches will be sufficient for all ordinary conditions, and for motors above this size from three to six or more switches may be required. In any case it does not pay to extend the number of switches beyond a point governed by the sensitiveness of the switch itself.

Fig. 12



TO START, PUSH STARTING BUTTON.
TO STOP, PUSH STOP BUTTON
WHICH OPENS R1 SWITCH AND
CLOSES BRAKING SWITCH GIVING
2 POINTS OF DYNAMIC BRAKING.
SECOND POINT DEPENDING ON THE
CLOSURE OF THE FIRST "A" SWITCH.

WIRING DIAGRAM
REAR VIEW

Fig. 13

The switch under consideration is sensitive well within ten per cent, that is to say, if the switch locks out positively at a given value of current it will close positively when the current has dropped ten per cent below that value. This means that the maximum and minimum accelerating current values can, with the requisite number of switches, be kept within five per cent above and five per cent below a horizontal line which represents a predetermined accelerating current of constant value.

In any calculations which are made as to the theoretically proper number of switches it must be borne in mind that the self-induction of the motor windings enters as an important factor, the peaks of current occurring at the instant of cutting out a given amount of resistance being in no case as great as a consideration of ohmic resistance alone would indicate.

FIG. 14

Figs. 12 and 13 show respectively a front view and a diagram of connections of a special controller for governing motors driving certain kinds of machine tools such as boring mills and pipe threading machines. In addition to securing automatic current limit acceleration in the manner previously described, this controller provides for bringing the motor to rest promptly by means of dynamic braking, the braking current being also kept within safe limits by the current limit feature of the switches which govern the acceleration.

This starter is provided with a main switch having a shunt-wound actuating coil and a dynamic-braking switch constructed in like manner. The operator's control is through push-buttoms marked " start " and " stop " respectively. When the " start " button is pushed the circuit of the actuating winding of the main switch is closed, causing this switch to close, and the starting resistance is then cut out automatically by the series wound accelerating switches in the manner previously described.

When it is desired to stop the " stop " button is pushed. This opens the circuit of the actuating winding of the main switch and closes the circuit of the winding of the dynamic braking switch, which then closes, establishing a local circuit across the armature, this circuit including the starting resistance and the actuating winding of the first resistance switch. As the motor slows down the dynamic braking current decreases and the first switch closes, thus cutting out a portion of the resistance in the dynamic braking circuit and at the same time closing the circuit through the winding of the second resistance controlling switch, which in turn closes and cuts out a second section of resistance when the current has dropped to the value for which the switch is adjusted. Both the starting current and the dynamic braking current are therefore under automatic current limit control and are maintained within safe limits.

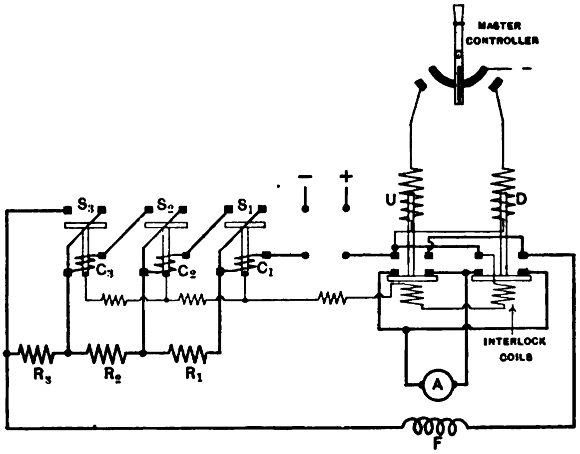


FIG. 15—Wiring Diagram

Fig. 14 is a front view of a 75-h.p. reversing controller specifically designed for steel mill service, and Fig. 15 shows the connections of this controller.

Reversal of the motor is provided for by two double pole magnetic switches having shunt wound actuating coils. The switches are mechanically interlocked in such a way that when one is closed the closure of the other is prohibited.

The actuating windings of the reversing switches are under the control of a suitable master controller in the hands of the operator. The motor circuit is initially closed at the contacts of one or the other reverser switches, this initial current flowing also through the winding of the first series wound switch. When the motor current has dropped to the predetermined accelerating value the first accelerating switch closes, short-circuiting the first section of resistance and establishing a circuit through the actuating winding of the second accelerating switch. The automatic cutting out of resistance continues in a similar manner till the motor is connected across the line.

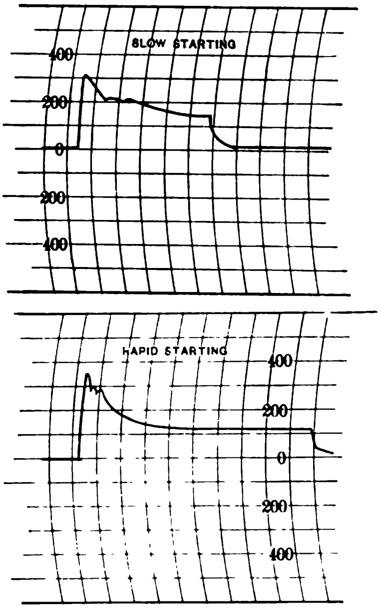


Fig. 16

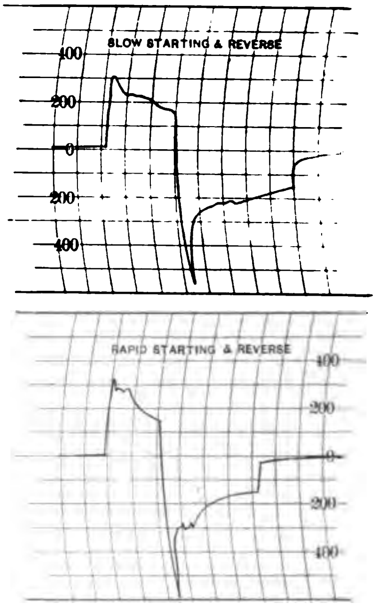


Fig. 17

The wiring diagram Fig. 15 shows a modified connection of the actuating windings of the accelerating switches, these windings being so arranged that they remain in series with the motor while the motor is running. A separate holding coil is therefore not required on the last switch.

As previously pointed out, the orderly or successive closure of the accelerating switches is provided for without the use of auxiliary or interlock contacts.

In a controller which is rapidly reversed it is essential to

FIG. 18

provide that all of the starting resistance be in circuit when the motor connections are reversed. This is provided for by two " lock-out " magnets placed immediately below the movable members of the reversing switches in such a way as to lock them out, thus preventing closure of the switches when the magnets are energized. The windings of these magnets are so connected that they are energized whenever any of the accelerating switches is closed. The reverser therefore cannot be operated until all three of the accelerating switches have opened, thus inserting all of the resistance in the motor circuit. It will be observed that this interlock is also obtained without the use of auxiliary or interlock contacts. The entire controller is in fact stripped of all small and delicate parts, in view of conditions to be met in steel mill service.

Figs. 16 and 17 are reproductions of accelerating current curves taken on this controller in connection with a 75-h.p. 220-volt series wound motor. Fig. 16 shows the accelerating curves in simple starting, under different adjustments of the switches to secure slow and rapid starting.

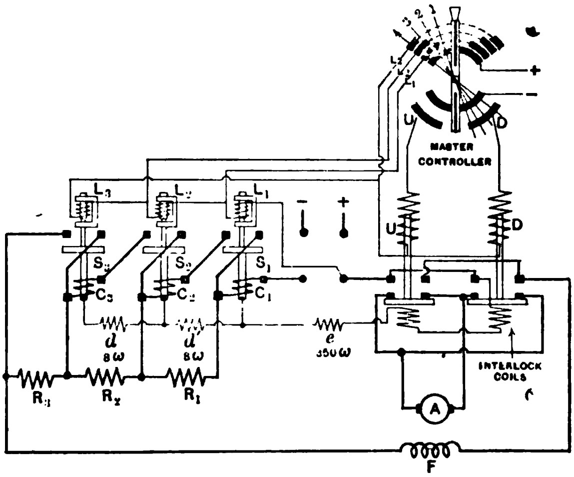


FIG. 19—Wiring Diagram

Fig. 17 shows current curves taken under similar conditions, the motor being reversed. Since there is no arcing at the contacts of the accelerating switches they may be readily enclosed in such a way that their adjustment cannot be tampered with.

The controller illustrated in Figs. 14 and 15 does not provide for speed control. Where it is necessary that the operator have control of the speed of the motor, this is provided for by " holding-out magnets " which prevent actuation of the accelerating switches when the " holding-out magnets " are energized.

Fig. 18 illustrates a unit switch equipped with a " holding-out magnet ", and Fig. 19 is a diagram of connections of a controller arranged for speed control. It will be seen that the " holding-out magnets " are successively de-energized as the master controller is moved toward the full speed position.

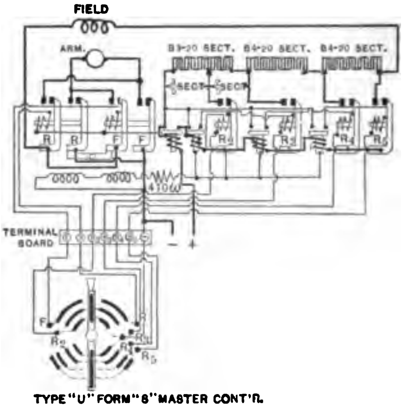


FIG. 20

The series wound switch in addition to its functions of a combined switch and current limit relay is of course adapted for use as a simple current limit or acceleration relay in connection with switches having shunt wound actuating coils.

Fig. 20 is a diagram of connections of a controller arranged in this way. It will be observed that this form of relay stands normally in the open or safe position and successive switches cannot close till the corresponding relays have closed their contacts. This arrangement provides a further safety feature in that it protects the motor from danger due to open circuits in the resistance and connections. The closure of successive resistance controlling switches depends not merely upon the closure of a preceding switch, but upon the closure of the main circuit controlled by a preceding switch. In case there is an open connection in the resistance controlled by one of the switches, the accelerating relay controlling the succeeding switch is not energized and the cutting out of resistance must stop at that point till the break is repaired.

DISCUSSION ON "AUTOMATIC MOTOR CONTROL FOR DIRECT-CURRENT MOTORS." CHICAGO, JUNE 28, 1911.

E. J. Murphy: I have listened with pleasure to Mr. Eastwood's able presentation, and can truly say that it represents a very great step towards the ideal which designers of control apparatus have been striving to attain, namely, an automatic motor control in which complicated wiring and numerous interlocks and relays have to a great extent been eliminated. It has been my privilege to work along those lines in which a contactor actuated by a series coil also contains the characteristic of a current limit relay. The illustrations shown and described herewith represent a type of contactor which was developed to meet steel mill operating conditions; in so doing it was decided to embody the best features of the shunt wound contactors which have proven so satisfactory after many years of the most exacting service; the most important feature being the reduction of the number of contact surfaces to a minimum, the use of a solid and easily replaceable rolling contact with vertical contact faces insuring against trouble due to the accumulation of dust or dirt upon them. The above consideration led to the adoption of a pivoted armature member which possessed the further advantage of operating with a minimum of friction, which is highly advantageous in obtaining a close and uniform adjustment. This arrangement of contacts also makes possible, when equipped with blow-out coils, the disrupting of heavy currents which is advantageous in certain applications of motor control. I wish to say, however, that this series contactor when used in an ordinary starting or reversing equipment is not called upon to open any appreciable current, making magnetic blow-out coils unnecessary. Your attention is particularly drawn to a very simple and effective method of connection, which makes it imperative that the contactors close in proper sequence, only one contactor being closed at a time. It should also be noted when the last contactor goes in, the other accelerating contactors are open while the motor is running. The above condition is brought about by means of the series coils only, no extra fine wire windings being necessary. This arrangement operates perfectly on a quick reversing equipment without any additional interlocking coils for delaying the action of the reversing line contactor.

Fig. 1 shows the contactor with the switch in the open position. C is a series wound actuating coil with a vertical iron core which projects through the brass supporting block B, and forms a pole face adapted to attract the cast iron armature A, across the upper air gap G_1. This armature is pivoted at P and carries the moving contact T, also the vertical iron strip L. The lower end of L forms a pole face which is attracted across the lower air gap G_2 by the horizontal iron extension E at the bottom of coil C. The armature A and the strip L form a bell crank lever: the attraction at the upper gap G_1 tends to close the switch and the attraction at the lower gap G_2 tends to hold the switch in the open position. The brass nut N, provided with locking spring, forms a stop for the strip L, thus regulating the length of the lower air gap G_2. This adjustment determines the current value at which the switch will close. (A more satisfactory adjusting device is shown in Fig. 2.) A vertical iron strip S of limited cross section connects the horizontal projection E and the iron casting to which the moving element is pivoted at P. This strip S forms a magnetic shunt to the lower air gap G_2, thus providing an alternative path for the magnetic flux.

The path of the magnetic flux is as follows: starting from the upper end of the core in coil C, across the gap G_1, along the armature A, to the pivot P where the flux divides, one portion flowing down the strip L, across the gap to the projection E. Another portion flows down the iron shunt S to the projection E. The total flux then flows along E to the magnet core of coil.

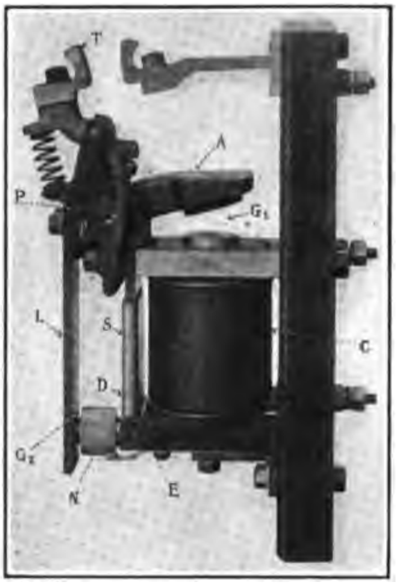
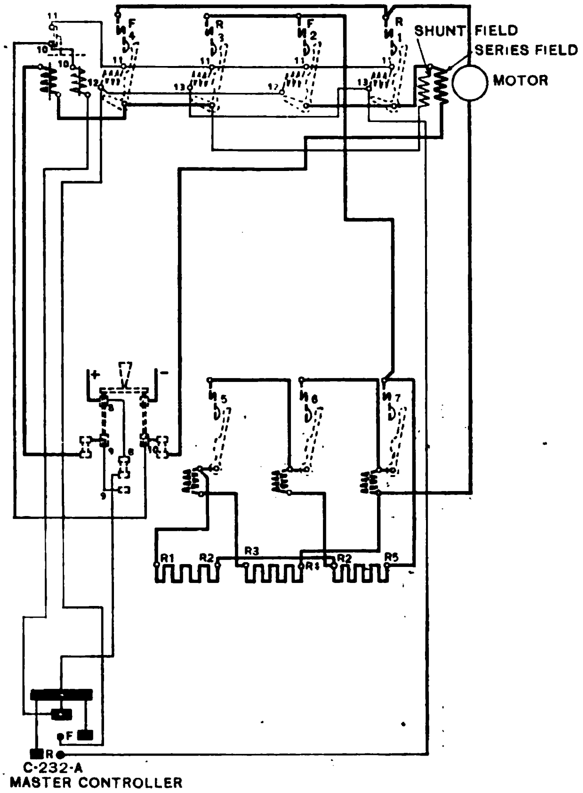


Fig. 1

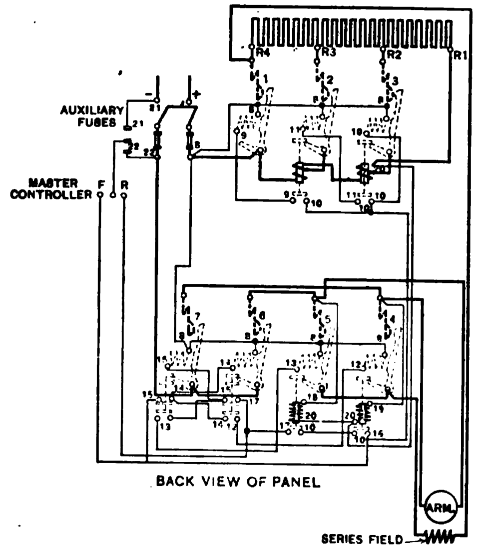
When current is switched through the coil C and this current is higher than the closing value for which the device is adjusted, the attraction across the lower gap G_2 is sufficient to hold the switch open against the attraction across the upper gap G_1. When the current falls, due to the acceleration of the motor, the magnetic flux in all parts of the magnetic circuit will decrease. The permeability of the iron shunt S will therefore increase, and in consequence, will carry a larger proportion of the flux relative to the lower gap G_2; these parts of the magnetic circuit being in parallel. The attraction across the lower gap G_2 will fall at a greater rate than the decrease in the attraction at the upper gap G_1, and finally, when the current arrives at the adjusted closing value, the attraction at the lower gap G_2 can no longer hold the moving element and the switch will close.

There was one serious difficulty which had to be overcome in the design, *i.e.*, to make certain that the contactor would hold open when the first rush of current through a highly inductive circuit was very little above the value at which the device was set to trip. This problem was solved by encircling the iron shunt S with a low resistance copper band D. The rapid rise in the flux value in the shunt S when the current is first switched on, generates a momentary heavy current in the copper band which opposes the increase of the flux. This action causes a larger proportion of flux to be forced across the gap G_2 while the current is rising, thereby increasing the attraction at the point until the current has risen to a safe value. In quick reversing equipments, the adoption of a longer copper band as shown in Fig. 2, rendered unnecessary the use of complicated interlocking devices.

FIG. 2



MECHANICAL INTERLOCK
BETWEEN CONTACTORS 1 AND 2, 3 AND 4
BACK VIEW OF PANEL



MECHANICAL INTERLOCKS BETWEEN 4 AND 5, 6 AND 7

Fig. 3

The flexible connection for carrying the current around the pivot presented another serious problem, inasmuch as the mechanical forces due to the stiffness or " spring " of such connection might interfere with the adjustment of the device. The arrangement shown in Fig. 2 effectually solves the problem. The connection consists of a loop of flexible cable of many fine copper wire strands. The plane of the loop is parallel to the axis of the pivot, and the axis lies in this plane. Any force due to the tendency of the loop to open or close, will be exerted, radially across the pivot, with no torque around the pivot. Actual tests proved the accuracy of the above assumption.

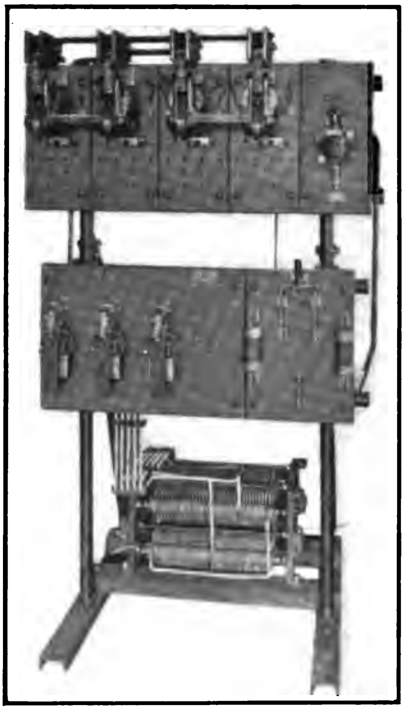


Fig. 4

In connection with the subject of series wound contactors in general, I note that Mr. Eastwood did not bring out one very important advantage, *i.e.*, the use of coil windings of few turns and large cross section of conductor. The construction shown in Fig. 2 is typical; the coil consisting of relatively few turns of bare edgewise wound copper strip with one end connected to the frame. This construction will stand very heavy overloads without damage. The potential strain across the coil and from coil to spool is only a fraction of a volt.

Fig. 2 also shows an improved adjustment for the lower gap G_2. The lower end of the vertical strip L abuts against the head of a fixed brass stud which supports an iron thimble. This thimble can be screwed along the stud, thereby controlling the width of the air gap G_2. Simple and positive locking devices are provided.

Fig. 3 shows the contrast between two connection diagrams for starting and reversing a direct current motor. The lower diagram shows the old fashioned arrangement with current limit relays operating shunt wound contactors with numerous electrical interlocks. The upper diagram shows the series contactor accelerating arrangement for the same duty, no electrical interlocks being required.

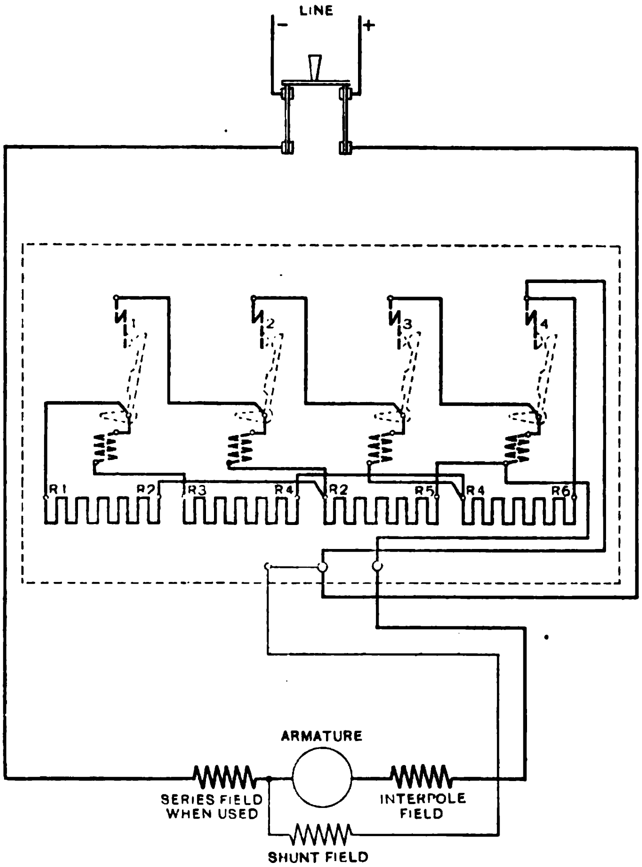


FIG. 5

Fig. 4 shows the front view of a starting and reversing panel using series accelerating contactors designed for heavy steel mill duty and Fig. 5 shows a wiring diagram of a very simple motor starting panel, using four series wound accelerating contactors with hand operated line switch and fuses.

Arthur C. Eastwood: As to the matter of contacts, brought up by Mr. Murphy, it must be remembered that this switch acts not only as a switch, but also as a relay. Whether the switch is a small one wound say for a one-horse-power motor, or a large one wound say for a 1,000-h.p. motor, when the current through the winding of the switch is reduced to a certain critical value the weight of the moving parts is just balanced by the magnetic pull. This is the sensitive point in the operation of the switch, and at this point the reliability of its action may be seriously disturbed by the friction of a pivot and by the variable action of the shunt which is essential in carrying current around the pivot in a switch of the single-break pivoted-arm type.

Experiments with switches of the pivoted-arm type did not give reliable results within prescribed limits of accuracy, and led to the adoption of the construction illustrated in my paper. In this construction there are no pivots, pins, or shunts. The plunger of the switch is mounted vertically, and the magnetic pull tending to close the switch acts against gravity, which is as nearly constant as anything we know of.

As to the matter of interlocks for reversing controllers, notwithstanding the fact that the series wound switch is very quick in action, in very rapid reversing service there is danger of the reverser being thrown before all of the resistance switches have opened. An interlock which will prevent this appears to be a safety precaution which is well warranted, particularly in controllers for reversing mill tables. Such tables are usually over-motored to secure very rapid acceleration and reversal, so that the motor will overspeed very quickly if it is series wound. If the motor while running at high speed is reversed with part or all of the resistance short-circuited, damage is very likely to result.

As to damping the magnetic circuit of series wound switches to prevent their too-early closure, this is not at all necessary in switches for use with shunt and compound wound motors. In fact, it is objectionable at least with the form of switch described in this paper, because closure of successive switches is unnecessarily retarded.

In the case of larger series wound motors, which give a circuit of high self-induction, causing the motor current to build up gradually, there is a tendency for the switches to close before the current has reached the lock-out value for which the switches are adjusted. However, the series wound switch is no more subject to this action than the ordinary "throttles" or accelerating relays which have been used in the past.

Even in the case of large series wound motors it has been found that if the resistance may be so proportioned that peaks of current equivalent to 150 per cent of the current at which the switch is adjusted to close, occur at the closure of each successive resistance switch, reliable locking-out of the switches occurs without resort to any specific means for retarding the action of the switches.

As to the matter of holding in the switches, this paper illustrates in Fig. 5 the use of a shunt holding coil on the last resistance switch, and in Fig. 15 the use of series coils throughout.

Admittedly the series coil is simpler in its connections and is more sturdy in construction, but its use has decided limitations. It has been found that in a surprisingly large proportion of motors, particularly those driving machine tools, the armature current frequently approaches very close to zero, and in the case of tools or machines equipped with fly-wheels, upon a sudden drop in line voltage the motor acts as a generator returning current to the line. This causes the last switch to drop out and insert all of the starting resistance in the motor circuit, and, when the motor has slowed down slightly, the resistance is again automatically cut out. This introduces an objectionable pumping action in many instances. The shunt holding-coil is free of this objection, as it leaves the motor connected to the line and free to return current to the line at the instant of a sudden drop in voltage.

The use of the series holding coil also introduces a resistance in the armature circuit which is objectionable in shunt wound motors where constant speed is required.

Ragner Wikander: I want to ask Mr. Eastwood and Mr. Murphy whether they have made any tests of the application of this principle, possibly somewhat modified, to alternating current?

Arthur C. Eastwood: In answer to the question as to the adaptability of this form of switch to alternating current controllers, I will say that experiments have been made in that direction which are very promising. I am not, however, prepared to go into detail on the subject at this time.

Theodore Varney: I would like to ask Mr. Eastwood if he has found any satisfactory means of notching back with the controller he described, that is, opening the switches one at a time, without opening all of them.

Arthur C. Eastwood: As to the question of " notching back " the controller, that is, reducing the speed of the motor step-by-step, the connections of the series wound contactors lose a great deal of their beautiful simplicity when this must be done.

There is no particular complication in a controller for " notching up " the speed of the motor step-by-step. Such a controller is shown in Fig. 19 of the paper.

When it is desirable to reduce as well as to increase the speed of the motor in a step-by-step manner under the control of the operator, a controller such as that shown in Fig. 20 may be used. In this controller the resistance switches are actuated by shunt wound magnets, and are governed as to the time of their closure by individual series relays.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

SOME LIMITATIONS OF RHEOSTATIC CONTROL

BY G. R. RADLEY AND L. L. TATUM

We may consider the limits of rheostatic control under three classes, *functional*, where the limitations are inherent to the type of control; *resistance material*, where the limitations are due to physical characteristics of the rheostat material, and *switching devices*, where the limitations apply to the method of adjusting resistance.

Functional Limitations

Under this heading, there are two general classes, those in which the load is predetermined, and absolutely under the control of the operator such as a field rheostat, and those in which the load is dependent on a variable factor, not absolutely of a predetermined value, such as a motor speed regulator with varying load on the motor.

In the first type, the field between actual physical limits is wide, but commercial limitations are worthy of consideration. Inherently all such devices are heat dissipators and the most important commercial limitation is the compromise of three variables; watts to be dissipated, allowable temperature rise, and physical dimensions. The discussion of these limitations which are common to all forms of rheostatic devices will be taken up later under the subject of " Limitations of Resistance Material."

Fineness of regulation is commercially limited. A field rheostat must be able to adjust the voltage of the generator by reasonably fine increments throughout the working range both of load and of speed of prime mover. If the range is wide, and the regulation desired is fine, the number of steps to obtain this range increases and while no physical limitations appear, the cost is increased. A fineness of regulation closer than ½ of one per cent of the rated voltage is ordinarily unnecessary, and generally this fineness may be obtained with a variation in excitation current of 1.5 per cent per step. For most machines 60 steps, thus representing in the neighborhood of 25 or 30 per cent of line voltage variation is ample. If, however, the major portion of this 25 per cent variation is outside the normal working range, then this number of steps may be insufficient. This condition may be overcome by the introduction of coarse steps in that portion of the range which is not normally used. For voltages above the working range, a single fixed step of resistance may serve to throw the normal voltage into the center of the adjusting range. Similarly below operating voltages a few coarse steps may be wanted for lowering the voltage to a satisfactory point for cutting out a generator.

Fineness of stepping over a wide range affects the size by increasing the watt dissipating material, as well as by increasing the number of switching points. Coarse steps tend to cheapen the rheostat but there are limits in this direction which will be discussed under contact limitations.

When a generator is capable of voltages much above normal, a fixed step of resistance results in economy of wattage capacity in the rheostat without approaching the contact limits, protects the machine from excessive heating of fields, and prevents excessive voltage on the line.

For use with automatic voltage regulators which require a wide range of generator excitation, coarse steps over most of the range with fine steps around normal, for possible hand regulation, reduces the size of the rheostat materially.

Another class of rheostatic device very similar in its functions to the field rheostat is the lamp dimmer. Here the conditions are even better defined than for the rheostat, as the dimmer is connected across a constant voltage supply in series with a quite definitely known resistance. The same general limitations apply, however: the coarser the stepping the smaller and cheaper is the rheostat.

.Typical of the second class, namely, the type of control where there exists in the circuit a variable element which may be independent of the adjustment of the rheostat, are motor starters, or speed regulators where the counter voltage of the motor may be dependent on the load as well as on the adjustable resistance. Arc lamp resistances are more or less similar in their behavior. For this type of apparatus the governing feature is " load ". Ohm's law must ever be in mind in considering such devices.

For a fixed value of R, E will vary directly as the current in the resistance, and when used as a speed regulating device across a constant potential line, the difference between the voltage drop in the resistance and the line voltage must be the counter e.m.f. of the motor. If the load on the motor varies, as when driving a machine tool such as lathe or planer, the voltage drop across the resistance must vary in direct proportion and the motor speed will vary inversely as the load. The inherently bad effect of such instability of speed regulation on machine tool work is too well understood to need discussion.

Where the load of the motor at any speed is approximately constant as when driving fans, pumps, printing presses, long line shafts, etc., resistance control is practical, although not always economical. Where the required torque decreases with the speed, as in the case of fans or centrifugal pumps the use of resistance is economical, since it reduces the current taken from the line, but where the torque is constant as for plunger pumps or positive pressure blowers, the only economy obtained by such control is in reduction of wear and tear on the apparatus, although convenience may warrant its installation independent of economical considerations.

On motor starters or regulators, the limit of coarseness of stepping is the increase in voltage the motor will stand without objectionable surge of current. This is a function of the motor and line resistance. A low motor resistance means a large current with small voltage rise at its terminals. A small high resistance series motor may not take an objectionable surge even if given full line voltage, while a large shunt-wound machine may not stand more than a few per cent voltage increase without excessive currents. This limit cannot be predetermined accurately as the inductance of the circuit, reaction of armature current surge on field strength, and momentary acceleration all tend to damp out the high peaks and give less than the calculated current surge for a given voltage increase.

This limit of stepping of resistance is most pronounced with the motor near normal speed or with little resistance in circuit. Theoretically for a 50 per cent overload surge we should be able to reduce the ohms in circuit to ⅔ the previous value whenever the current has fallen to normal. This means that the ohmic value of the steps decreases toward the short circuit end.

This limits the arrangement of the steps on speed regulators since a regulator must also perform the functions of a starter.

If equal percentage increase in speed per step is wanted, (a geometrical progression) the last steps must be larger than the first, but this is the reverse of what is possible with equal surges. If equal speed increments are wanted, (an arithmetical progression) the steps should be of equal ohms, approaching more nearly to the starting requirements, but a compromise between the desirable speed curve and good starting characteristics must generally be made.

While the coarseness of steps is thus limited, there is no functional limit to the fineness of them, commercial considerations alone governing this.

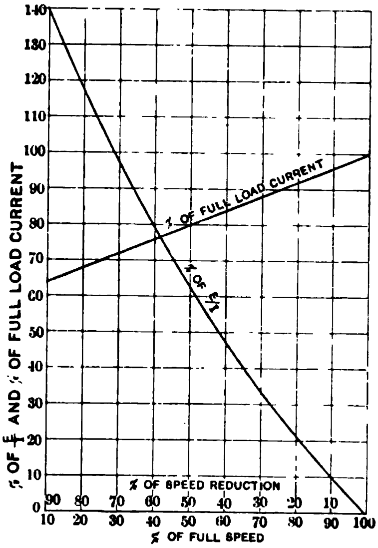


Fig. 1—Relation between speed, current and resistance assumed for machine regulation design.

Two distinct types of armature speed regulating devices are commercially recognized. These are commonly known as " machine type " and " fan type ". Machine type is suitable for motors where the torque or current necessary for operation of the motor is approximately constant.

Fan type is the term applied to devices where the torque falls off as the speed decreases. As it is often impractical to determine the actual load a motor is to drive, one manufacturer designs a machine type regulator for 50 per cent reduction in speed with 80 per cent of the rated motor current thus allowing for the desired speed regulation with a 20 per cent variation in the actual load. If the motor runs at its full rated current, the speed reduction possible with all resistance in circuit will then be 62½ per cent.

The relation of resistance necessary to give any desired decrease in speed on the assumption that the load current follows a straight line from full load at full speed to 80 per cent of load at half speed is given in Fig. 1. The resistance is expressed in per cent of line volts divided by rated current of motor, thus making the formula applicable for all voltages and motor ratings. Fig. 2 shows a similar curve as laid out for the typical fan load. Theoretically, the horse power of a fan varies as the cube of the speed. Its torque therefore varies as the square of the speed and the current in the armature circuit should vary as the square of the speed. The friction losses will, however, vary directly as the speed, so that the total current in the motor armature should vary along a line between a straight line and the square curve. The effect of the friction losses will be much greater with small fans and at low speed and Fig. 2 therefore gives several current curves for motors of different sizes, the large sizes approaching more closely to a square curve, while the small sizes more closely approach a straight line.

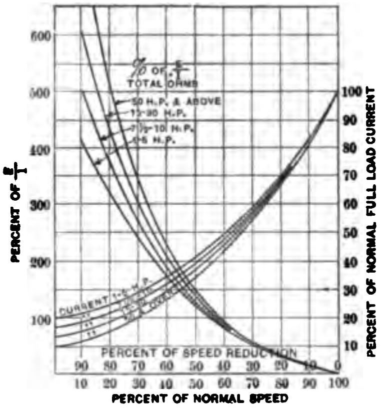


FIG. 2—Curves for fan regulation by armature resistance.

From an inspection of these curves the fact becomes apparent that the characteristics of the load, including its limiting variations, must be known if accurate speed control is expected from commercially standard apparatus.

There are some calls for more than 50 per cent speed reduction for special purposes. Ninety per cent by armature resistance may even be necessary. If 90 per cent of the line voltage is dropped in the resistance with a given current, it is evident that an increase of 11 per cent in current value will increase the resistance drop to full line voltage and leave nothing for counter voltage. If the current decreases 11 per cent the resistance drop falls to 80 per cent and the motor speeds up to double the desired speed. For such wide speed reductions by straight series resistance it is therefore necessary that the load be determined very accurately. These low speeds may be steadied by the use of a resistance in shunt to the armature. The effect of this is to make a portion of the current in the series resistance, and thus part of the voltage drop in the resistance, independent of the variations in motor current. The practical limit of this scheme is the amount of energy that may be wasted in the resistance. If the motor current in the armature is infinitely small compared to the line current, then its variation may be very wide with inappreciable change in resultant voltage at the motor terminals. A large wasted current is not only uneconomical but impractical. The armature shunt is only needed at low speeds, say below 25 per cent of normal. The next higher speed would be with straight series resistance. The load and desired speed determine the ohms at this point and thus set the maximum value of the total current. Greater currents would mean a bad jump in speed while lower currents give less steadying of the low speed. By the following formulas the values of shunting resistance may easily be determined for any given set of conditions.

Let E = line volts.

E_a = volts counter e.m.f. of armature.

R = ohms series resistance. This is dictated by desired speed with series resistance only.

R_a = ohms armature and brushes. May be neglected where $E_a > 20$ per cent E. For lower values of E_a, R_a may be taken: 10 per cent E/I for 5 h.p., 5 per cent E/I for 50 h.p., 3 per cent E/I for 200 h.p.

I_a = armature amperes—if not known may be estimated.

R_s = ohms in shunt. This will usually be the unknown. Derived from given values of I_a, derived values of R, known values of E and R_a, and desired values of E_a.
I_s = current through armature shunt, R_s.
I_r = current through series resistance R.
E_s = voltage across armature shunt, R_s.

Then

$$I_r = \frac{E - E_a - I_a\,R_a}{R}, \quad I_s = I_r - I_a, \quad E_s = E_a + I_a\,R_a$$

and

$$R_s = \frac{E_s}{I_s}, \quad \text{or } R_s = \frac{R.E_a + R.I_a\,R_a}{E - E_a - I_a\,R_a - R.I_a}$$

NOTE:—For constant field strength the speed in per cent of normal will vary as the counter e.m.f. of the armature in per cent of the counter e.m.f. at normal speed. This counter e.m.f. or E_a at normal speed equals $E - I_a\,R_a$ or line volts less resistance drop in the armature. $I_a\,R_a$ for speeds above 20 per cent and for large motors may be ignored.

RESISTANCE MATERIAL

The limiting features in the resistance material, or resistor, appear in getting the current into the resistor and getting the heat out of it. The limits for various materials used as resistors are sometimes found from one factor and sometimes from the other. Consider in a general way the matter of getting current into a resistor. Since the resistor is specifically designed for the dissipation of heat, we should expect it to reach a fairly high temperature. While the resistor itself may be of a material which will stand high temperature without oxidation or deterioration of its surface, the material commonly used for connectors, or conductors to such resistors, is subject to deterioration at reasonably low temperatures. It is necessary therefore, that the terminals of the resistors be specially designed to hold down the temperatures at this point. A terminal attached to a hot resistor must necessarily heat considerably by conduction, and if to this conduction is added a considerable amount of internally generated heat, the temperature is apt to be abnormally high. A gradation of temperature is wanted between the lead wires and the resistor itself, and the temperature of the lead wire and terminal should be kept low enough to prevent the melting of solder. One of the best examples of trouble with terminals is in the use of carbon resistances. Here the resistance of the contact is generally higher per unit of area than that of the resistor. Since the current is necessarily the same in resistor and terminal, this local increase in R means local heating and the use of carbon or graphite disk resistance which has many most excellent qualities has been limited by this terminal trouble. The same is true of water resistances. The highest resistance is ordinarily at the electrodes causing local heating.

How to get the heat out of the resistance is determined by a study of the laws of the flow of heat. The heat can be dissipated by radiation, by conduction, or by convection currents of fluids. All three methods are usually available to a greater or less extent. In the case of enclosed resistances it is almost entirely conduction from the wire to the exterior surface. In the majority of cases, the final disposition of the heat is into the air, the greater portion of this being by convection currents at ordinary temperatures, although at high temperatures, radiation plays a very important part.

Since practically all of the heat from a rheostat must be carried away by the air the actual design for a given limiting temperature both of issuing air and of rheostat exterior must be based on the laws of ventilation. The highest efficiency occurs when for a given amount of resistance material the quantity of air passed through the rheostat becomes a maximum. Vertical flues are more effective than horizontal baffles. The higher the temperature of the flue the more rapid the convective air currents and the greater the permissible watts for a given top area. What shall we take as a limit? Pieces of paper, wood, cloth, etc., begin to char at about 225 deg. cent., or 200 deg. rise above the usual room temperature. A 150 deg. cent. rise would then seem to be a safe point to choose for a limiting temperature. But this limit need only apply to the parts of the rheostat which may come in contact with external objects. With embedded rheostats this would mean the case. In the open type, the resistor itself would be measured. But where the resistor is provided with a frame and has screens to prevent the entrance of foreign combustible material into the enclosure, the temperature limit of 150 deg. rise should apply only to the *top* or hottest part of this frame. The interior heating surfaces or flues should be permitted say double this, or 300 deg. cent. rise. There would then still be a considerable factor for unforeseen overload before reaching a red heat, which occurs at from 500 to 600 deg. cent.

With these maximum limits established it then only remains to consider the resistor materials and the temperatures they may stand without deterioration. For alloys such as German silver this is the point at which the zinc distills off, changing its characteristics as a resistor. For alloys containing manganese, the distilling point of this metal is the limit. For wrought iron or iron wire, the limit is the temperature at which the resistor becomes plastic, which is close to that at which oxidation becomes bad. Cast iron can be run indefinitely at a dull red heat, with only very slow oxidation, but at white heat the oxidation is much more rapid, and the melting point is the final limit. For carbon or graphite, a bright red heat allows slow oxidation but without immediate deterioration.

While these are ultimate temperature limits, a factor of safety is desired and the limiting of the air temperature tends to hold temperature of resistor much lower. As a rough average of commercial structures with natural ventilation, the surface temperature of an open resistor, such as a cast iron grid, will be about 350 deg. cent with the air issuing from top of frame at 175 deg. cent. The temperature of an imbedded resistor may be much higher than the surface of the enclosing material, and this temperature gradient from resistor to surface will vary greatly with the kind of material.

Probably the best way to bring out some of the limits of resistance material will be to consider specific forms. For very large currents used only for emergency, or tests, a water rheostat is admirably adapted. The boiling point of the water is the temperature limit, but terminal troubles are the main factor. It is comparatively easy to get the current into the electrodes, but the high resistance between the electrodes and liquid conductors limits the current which can be carried per square inch of electrodes. This varies with the liquid, and also to some extent with the nature of the electrodes, so that no specific figures can be given here.

For large currents one naturally turns to iron for a cheap and sturdy resistor. Old rails have been used in some specific instances, but here the trouble is mainly one of getting the current into the resistor itself. A 30-ft. 60-lb. rail has a resistance of 0.001 ohm approximately. When used for very intermittent service, such as starting a large motor, it will absorb 220 kw. for one minute with a temperature rise of approximately 100 deg. cent. To get 220 kw. into the rail with a resistance of 0.001

ohm, means the use of 15,000 amperes, and the shape of a 60-lb. rail does not readily lend itself to the attachment of 15,000 ampere terminals. For regulating duty its shape makes it inefficient.

The limit of temperature of wrought iron or steel resistors is the plastic stage. To prevent deformation under their own weight would require frequent insulating supports, making such structures expensive and generally reducing ventilation.

Cast iron as a resistance material is cheap, easily formed so as to give good arrangements for terminal attachments, easily adjusted in section to the desired resistance, and has an extremely narrow temperature range during which it is plastic. Ordinarily if the plastic temperature is reached, it will very quickly pass to the melting point and the grid instead of remaining in circuit badly damaged, will melt and open the circuit.

Cast grids reach the limit of heavy currents due to terminal features, while with low currents the limit is the ability to get sufficiently high resistance. By casting the grid with considerable mass of metal at the point of terminal connection, the generation of heat in the terminal due to its own resistance is reduced. The conducted heat from the hot section is dissipated from the large terminal surface at a low temperature. The terminals may also be placed out of the heated air flue and in a column of comparatively cool air. Manufacturing conditions limit the size of these terminal lugs, and since the current is carried from one grid to the other through the surfaces of these lugs, this current capacity between lugs becomes a limiting feature. In ordinary commercial practice this limiting feature coincides fairly well with the limits of current capacity of wires which are easily handled for attachment into such terminals. About 300,000 cir. mil stranded wire is as heavy as should be used. When carrying current continuously this means about 400 amperes, while when worked very intermittently, it may be used up to 1200 or 1500 amperes. This is the top limit that should be used on a single circuit, and greater currents should be divided on parallel circuits.

The resistance that can be obtained determines the low current limit of cast iron grids. A section 3/32 by $\frac{1}{8}$ in. by 8 in. long can be cast, but a long section, or several loops of this size will scarcely support its own weight, and must be supported. Cast iron varies a little in its specific resistance, castings from the same heat running about 500 ohms per cir. mil-ft. for heavy sections and a little higher, or about 550 ohms, for very thin sections. The thinnest practical section grid is commercially economical for continuous current dissipation down to about 20 amperes, but below that weight, space, and cost must be sacrificed.

Attempts have been made for years to find alloys of iron having a higher specific resistance, to extend the economical range of this construction below the 20-ampere limit. The high cost of these alloys has so far prevented their commercial adoption. Alloys of copper, nickel and other metals which have very high specific resistances are practically useless for this structure, because of their plastic stage being reached at comparatively low temperatures with the result that they distort under commercial operating conditions. The high cost of the alloy itself combined with the relatively low temperature at which it must be worked, makes other forms of supported material much more economical. While above 20 amperes continuous duty the cast grid has no serious rival, below 20 amperes some other form is necessary.

Space and weight consideration necessitate a resistor of high specific resistance. Iron wire meets this condition economically, but its high temperature coefficient and liability to rust, limit its field to fairly low temperatures. High resistance alloys are expensive and their commercial use requires that the weight be kept down to a minimum. More heat can be carried away from a wire by conduction through even poor heat conductors, than by convection of air and radiation, for a given temperature above the surrounding medium. This has led to covering such resistors with cement, enamel or mica, conducting the heat from the wire and distributing it over a larger surface from which it passes to the air with a lower surface temperature. Alloy resistance wires are generally plastic at comparatively low temperatures. This necessitates frequent points of support.

The limits of stiffness of resistor and its inherently small surface have led to a form consisting of a heat resisting insulating base, on which the wire is wound, and some heat resisting insulating covering attaching the wire to the base. The high current limit of such construction is primarily its cost, where cast iron grids can be economically used, coupled with difficulty of winding and clamping heavy resistor wires, and of bringing out suitable terminals. Unequal expansion of resistor and covering crack the latter if the wire is too heavy. There is no low current limit to such constructions. The resistance that can be put into a given space is limited only by the size and specific resistance of the wire obtainable.

The temperature limit of such resistance units is much the same as for cast grids. For the same temperature of air, 175 deg. cent. approximately the same temperature of unit surface may exist, about 350 deg. cent. The actual temperature of the resistor will vary widely with the thickness and nature of the covering over it. Alloys are obtainable which will be stable up to even 1500 deg. cent. while the covering will generally deteriorate at red heat or a little above.

For continuous duty the order of limitations for such units is, first, temperature of issuing air, second, temperature of covering and third, melting point of the resistor. When used for intermittent or starting duty the order of the limits may be reversed. It takes some time to heat up the resistor covering to a point where it will give up heat to the air. The entire heat generated during a period of service may be absorbed by the unit and only gradually conducted to the exterior.

With a heavy covering of low heat conductivity the maximum surface temperature may not be reached till several minutes after current is cut off. This indicates a steep temperature gradient in the covering. If the rate of heat generation in the resistor is higher than conduction can carry it away, the temperature of the resistor must rise. Up to a certain point this rise in temperature seems to increase the rate of heat conduction and a balance is reached if given sufficient time. There appears however, to be a limiting rate of watt dissipation for a given wire, above which the resistor melts or vaporizes almost as soon as current is put on, acting very much like an enclosed fuse. When this action has occurred it is easily detected by examination of such a damaged unit. If gradually overloaded the resistor opens at the weakest point, and shows evidence of high heat on the covering. If suddenly overloaded to this limit the temperature rises so rapidly that the weakest spot does not have time to interrupt the circuit before several other spots have melted and opened the circuit, apparently simultaneously, yet without any evidence of overheating showing on the covering.

For momentary, intermittent or starting duty, the order of limits is therefore first the temperature of the resistor, second that of the covering and third that of the air.

CONTACT LIMITS

The limitations of contacts or switching parts are carrying capacity, and commutating capacity, the latter including ability to make, as well as break a circuit.

The carrying capacity of a contact cannot be defined accurately by a current density per unit of area of contact, but involves the material of the surfaces, the pressure per unit of area, and the mass and surface adjacent to the contact.

Of the commercially possible materials silver is probably best. It has a fairly high specific heat and good heat conduction, and the oxide is a good conductor. The latter is the main point, as the insulating oxide of other metals tends to reduce the area of contact.

Copper, brass and carbon follow in the order given.

While carbon has a relatively high specific resistance and high contact resistance it is used very extensively as a material for sliding contacts because of its freedom from welding, and its ability to withstand local high temperature without injury.

Laminated copper leaf brushes giving a well distributed pressure over the contact area are commercially best for large currents.

Contacts or switching devices in connection with rheostats must generally commutate current as well as carry it, and this feature limits the use of the various forms.

A sliding contact can make a circuit only through a leading point or line. Where this circuit parallels another circuit of relatively high resistance nearly the entire current passes through the line contact. This tends to heat the contact locally. If there is a good mass of heat-absorbing material closely adjacent to the line, the actual temperature rise may be small, but if there is little mass the line may quickly reach the fusing point. With copper or brass this may result in welding; with carbon it will cause burning.

These considerations lead to the limits of capacity of forms of contact. Round buttons make contact with the shoe practically at a point, and the curved shape reduces the adjacent mass. Segment forms make contact on a line, with larger masses adjacent. Knife blade contacts make one, or with very good fitting, two line contacts with small mass. The " butt " type approaches surface contact, and if of massive form has the mass adjacent to all parts of the surface. A butt contact with a light spring is no better than a sliding contact.

On making a circuit the current tending to heat the point of contact is determined by the resistance in circuit and the voltage. For the same current the heating is the same no matter what the voltage. On opening a circuit the voltage is the controlling factor. Below about 27 volts, no arc will form, and the heating ceases when the surfaces separate. Above this an arc tends to form, with heating and burning. If the contacts are cold and massive, and the current small the arc may not heat enough metal even locally to maintain itself. Either high voltage or high current, or to consider both, a high energy loss, tends to neutralize the effect of mass by heating the arcing point faster than it is cooled by conduction.

This is illustrated by the arcing distance of inductive circuits. On a test of the length of arc maintained when one or more magnetic switch circuits were opened, using heavy copper contacts, separated at slow speed, it was found that up to a certain current for any given voltage the arc would not hold 0.01 in. The smallest current that would arc this distance would often arc across a gap five times as large. Raising the current value would often run the arcing length up faster than the current. These values would have been materially changed for contacts of different weight and shape.

There are five factors that limit the amount of resistance than can be cut into circuit; first, the voltage, determined approximately by the current times the resistance of the step. Since there is generally some induction in a circuit, tending to maintain the current at its initial value, the value of the current existing before the introduction of the resistance must be used. Second, the value of the current. Third, nature of the contact, Fourth, the length of the gap. Fifth, the speed of operation.

Below 27 volts the length of the gap need not be considered, but the other factors all enter by reason of local heating on reduced surface of contact.

Above 27 volts, unless the currents are small compared to mass of contacts, gap length is important and becomes a definite limiting feature on sliding contacts which must bridge the gap. Filling the gap with insulating material to prevent the moving contact from falling between the fixed contacts, is dangerous as the arc drawn over the surface carbonizes the insulator, even if contact dust does not form a leakage path over its surface.

Step voltages therefore limit the use of sliding contacts.

Knife blade contacts may be used when handled quickly to eliminate the effect of small surface and small mass. Butt contacts generally supply the mass element.

Applying these limits to types previously considered, we find that for field rheostats or dimmers, having relatively light contacts, small spacing, and slow or indefinite motions, stepping of resistance must be small to prevent arcing on cutting in resistance, and still smaller to prevent shunting too large a portion of the total current through a line contact when coming in or going off a contact.

On a motor speed regulator with sliding contacts and a device for holding the moving contact squarely on the fixed contact, coarser steps may be used as the local heating effect is eliminated. On a motor speed regulator having a switch form of contact the steps may be as coarse as the switch will open.

On a motor starter with sliding contacts the steps may be coarser than on a regulator as the service is intermittent and heating effect reduced. The resistance is not normally cut into circuit slowly, so the arcing effect of the voltage per step may be neglected. When stopping a motor by a resistance starter the current in the starter is low by reason of the motor counter voltage nearly equalling line voltage.

In conclusion it may be well to state a few factors which will serve as short cuts to the consideration of sizes of rheostats. The maximum energy dissipation in an adjustable resistance in series with a fixed resistance across a given voltage occurs when the adjustable resistance in circuit is equal in value to the fixed resistance.

When the voltage over the rheostat, varies as a result of changing its resistance, (as in a field regulator or dimmer) the series connection of steps makes the most efficient use of resistance material.

When the voltage over the rheostat, however, does not change greatly with a change in its resistance, parallel connection of steps gives the best use both of resistor and of contact material. A load rheostat, which is used in series with an external resistance of negligible value, is an example of this. Here each step is arranged to pass a certain current, and at maximum load all resistance material is active.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

ELEVATOR CONTROL

BY T. E. BARNUM

The elevator problem is really one of service, and the general character of the elevator equipment must depend upon the character of service to be rendered. The service to be rendered by an elevator depends upon the number of passengers carried and the number of floors served; and is limited by the time taken by passengers entering and leaving the car, and the time required for acceleration and for retardation, as well as the actual time spent in traveling at full speed.

The engineer is then called upon to bring about the most effective combination of lifting power, speeds, acceleration and retardation for the requirements of a given building.

For the small office building with two or three elevators, express service to the upper floors is not possible, so that each elevator is required to stop at any floor. This often means stopping at every floor. Under these conditions the important factor is the ability to start and stop the elevator quickly and economically. The question of hoisting speed is of minor importance, as the schedule time for a trip depends so much upon the time taken to start and stop.

For the large office building, a sufficient number of elevators is provided, so that express service is possible on some elevators, and here the question of speed is of importance. However, for a part of the distance traveled local service must be rendered so that the capabilities of a quick start and stop can not be neglected.

In spite of the fact that the elevator may have to stop at every floor and that under these conditions it can not attain full speed, the capacity of the elevator in passengers per hour is a maximum when the car is full, that is, starts with the car full to distribute the passengers to the several floors, and in returning reaches the main floor full of people. This result follows from the good speed regulation of the shunt motor over its full range of load. The condition is not the same with a hydraulic elevator, as the speed varies with the load and the capacity of the elevator in passengers per hour is a maximum when loaded to 60 to 70 per cent of its capacity.

Two types of electric elevators have been developed to meet these services; one, the worm gear drive with moderate speed motor, the other, the gearless drive with special slow speed motor. I propose to discuss these two principal types with special reference to office building requirements, and by an analysis of some control systems and elevator performances to bring out their principal features.

The worm gear drive is used with a winding drum for short rises, and with the traction type of hoist when the rise is large. While the use of the worm gear results in a loss in efficiency from the motor to the load, this loss can be reduced to a reasonable amount by a correctly cut worm and worm gear, and the use of ball thrust bearings. The gear drive permits the use of a moderate speed motor of low cost, and high efficiency, and what is most important, with a wide range of speed control by field resistance. This speed control gives economical operation at a comparatively low speed and with certain classes of elevator service results in such an increase in electrical efficiency as compared to the gearless motor as to offset entirely the loss due to the gear drive.

In general the best results have been obtained by using an adjustable speed motor with a 2 to 1 speed range by shunt field control. This gives an economical speed of one half of the maximum, which will be called the normal speed of the motor or elevator. Under a given load, the horse power output of the motor at this normal speed is one half its maximum, and it is possible to proportion the starting resistance and the current inrush for acceleration from this lower value, and obtain prompt acceleration. This also gives the operator positive control of the elevator speed, so that he can slow down to half speed quickly regardless of load. This also returns some power to the line.

It is, of course, necessary to give the operator a still slower speed in order that he may make an accurate landing easily. This slow speed is obtained by introducing resistance in series with the armature and by shunting the armature with a section of resistance of low ohmic value relatively. In this way it is possible to give a slow speed of 25 per cent of the normal speed that does not vary very much with the load in the car. The elevator operator thus has an effective speed range of 8 to 1.

Diagram No. 1 shows in developed form the circuits for such an elevator motor. The switches of the controller are indicated by X. The motor armature circuit is controlled by three switches, the ***main switch***, and the two poles of the ***reverse switch***. This arrangement also disconnects the armature resistance, the series brake coil, and the series field winding from both sides of the line in the " off " position of the controller. The shunt field of the motor is partially energized in the " off " position; the ***field weakening switch*** is closed but the ***field relay*** is open, leaving the ***field maintaining*** resistance in circuit. The principal reason for this is to obtain a quick start. The slow speed is obtained with the main, reverse switch and dynamic brake switches closed, and of course with full field strength by closing both the field weakening switch and the field relay. The coil of the dynamic brake switch is connected to the motor armature so that this circuit is kept closed in stopping until the motor comes practically to rest, and the braking effect of the current generated in this local circuit is available at all times to assist the mechanical brake.

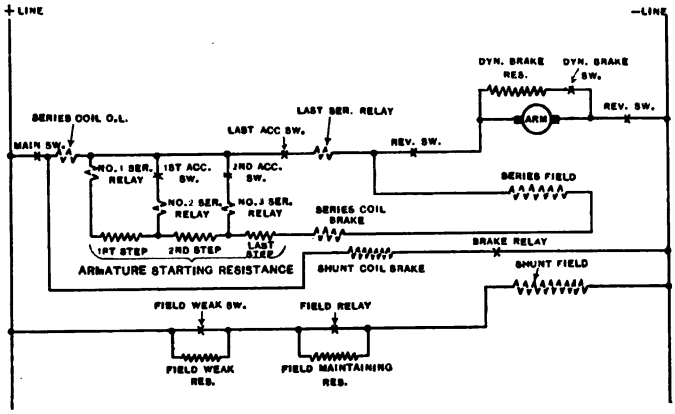


DIAGRAM No. 1

Where the elevator runs at a fairly high speed, it is not possible to get a smooth stop from the mechanical brake alone without excessive coasting. Excessive coasting is objectionable because of the varying amount of " coast " with varying loads. It is thus impossible to set the limit switches to stop the elevator with maximum load and to have the car come sufficiently close to the landing at light loads. The energy stored in the moving mass is proportional to the square of the velocity. The mechanical brake is capable of absorbing this energy in direct proportion to the velocity, only. While the dynamic brake will dissipate energy proportional to the square of the velocity, the mechanical brake is necessary, and a judicious combination of the two gives highly satisfactory results.

The mechanical brake is released by power and is applied by a spring or weight. The brake magnet has a series and a shunt winding; the brake being held released by the shunt winding only, but the two working together to raise the brake shoes. This arrangement reduces the size of the brake magnet and at the same time gives an interlock such that the brake cannot be released until the motor armature is connected to the line.

The acceleration is controlled by the four series relays. No. 1 series relay controls the cutting out of the first step of resistance, No. 2 the second step, No. 3 the third step, and the last series relay controls the opening of the field weakening switch, and therefore the increase in speed from normal to maximum. It has been found possible to cut the field weakening resistance into circuit in one step, and obtain a very smooth acceleration, because of the damping effect of the series field winding which is short circuited on itself through a path of low resistances. The field weakening switch is made so that an arc is permitted to form momentarily as the switch opens, thus assisting in the gradual reduction of the shunt field current. This arrangement for weakening the field gives a very smooth acceleration and simplifies the controller.

Diagram No. 2 shows in developed form the control circuits for this elevator. The car switch lever is a segment which connects contacts 1, 2, 3 and 4, either side of the " off " position. In general the opening of a control circuit anywhere results in the slowing down or the stopping of the elevator. The coils of switches controlling directly the starting of the motor are in series, these being the two coils of the reverse switch, the brake relay and the main switch. The brake relay opens one side of the line to the shunt brake coil, and also operates the shunt field relay. This circuit is opened to stop the elevator by the operator from the car switch, by the machine limit switch, which is two-pole, by the overload relay, by the overtravel limit switches, by the overspeed switch, by the slack cable switch or by the car safety switch. If the car is stopped by the machine limit switch, as is the case ordinarily, the operator may reverse the elevator by reversing the car switch. If the overload relay stops the car, the shunt coil of the relay connected to contact No. 1 holds the relay up and its circuit open until the car switch is moved to the " off " position. The overload relay can thus be reset at any time from the car switch. If the car is stopped by any of the other switches, it can not be started again until some one goes to the machine and takes care of the part causing the switch to operate. The slow speed relay controlled through contact No. 3, controls the set of switches for accelerating the car, and the dynamic brake switch. When this circuit is opened the armature resistance is cut into circuit and the dynamic brake switch is closed. The machine limit switch also opens this circuit to slow the motor down before stopping. The field weakening resistance is cut into the field circuit by energizing the field weakening switch, so that opening this circuit slows the elevator down to normal speed.

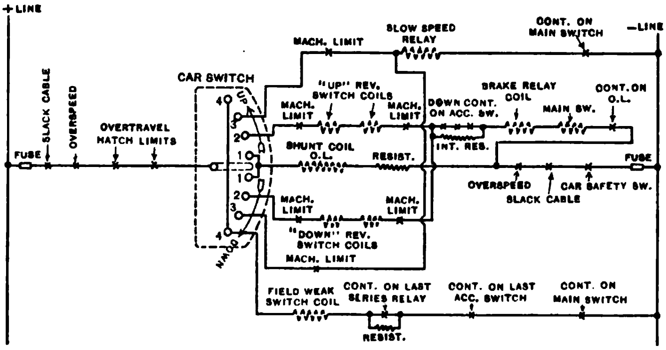


Diagram No. 2

Also as far as possible switches in the main control circuit are double pole, or the equivalent. Although the car switch itself is single pole only in one side of the line to the controller, a car safety switch is installed within reach of the operator which is connected by a separate two-wire cable in the other side of the line to the controller. The machine limit switch, slack cable switch, and overspeed switch are double pole, as shown. Of course, where the machine is of the traction type, the limit switches are installed in the hatchway, and operated by the car itself.

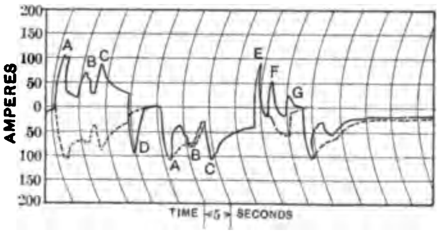
In the circuit including the main switch and reversing switch is an interlocking resistance so proportioned that the switches will not close if this resistance is in circuit. This resistance is short circuited only when all of the resistance switches are open, so that the motor circuit cannot be closed unless all the armature, starting resistance, the series field and the series brake coil are in the circuit. This arrangement makes it possible to reverse the elevator quickly, or to "plug" the motor.

Fig. 1 illustrates the switchboard of a controller having general connections as shown in Diagrams 1 and 2. The performance of such a controller is illustrated by Curves No. 1, 2 and 3. These and the other curves shown were taken by two recording ammeters, coupled together so as to synchronize. One ammeter was connected in the armature circuit and the current indicated by this instrument is shown by the full line. The other instrument was connected in the line circuit and this current is shown by the dotted line. Having these curves and knowing what the various current peaks mean, it is possible to tell just what the motor was doing.

FIG. 1

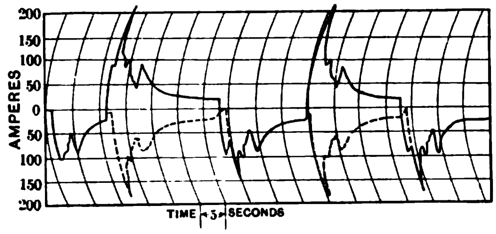
The dotted line showing the line current reads positively below the center line on some of the curves and above the center line on the others. By following the text and noting carefully the relation of the armature current and line current to the operation condition of the elevator, it is very easy to understand the curves.

In order to show what the various current peaks mean, the car switch was moved to the full speed position step by step. The result is shown by Curve No. 1. Current peak *A* is obtained when the car switch is moved to the first or slow speed position. While running on this point the line current is greater than the armature current, as the armature is shunted by the dynamic brake resistance. Current peak *B* is obtained when the car switch is moved to the second or normal speed position. This opens the shunt around the armature and cuts out the starting resistance. Current peak *C* is obtained as the switch is thrown to the third or maximum speed position, weakening the shunt field and doubling the speed of the motor and elevator. The car switch was then thrown quickly to the "off" position, giving the dynamic brake current peak *D*. The car switch was then thrown in the reverse direction, reversing the elevator, and giving the same three current peaks *A*, *B* and *C*.



CURVE No. 1

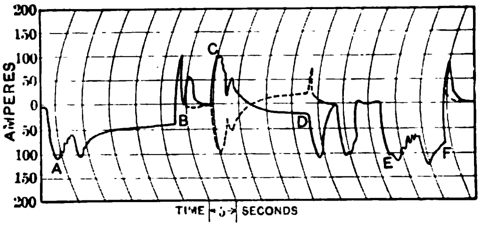
The car switch was then moved step by step to the "off" position. Moving the switch back to the normal speed position strengthens the shunt field and gives current peak *E*. It is to be noted that some current is here returned to the line, changing from a positive or power current of about 50 amperes to a negative or braking current of about 90 amperes. Moving the switch to the slow speed position gives current peak *F*, and moving the switch to the "off" position gives current peak *G*.



CURVE No. 2

Curve No. 2 was taken from the same elevator, showing first automatic acceleration from rest, and then "plugging" the motor. The steps of armature resistance and the weakening of the field can be seen readily. Note that the controller always starts to cut resistance out of the circuit at about 100 amperes.

This is the result of the series relay system of automatic acceleration. Note also the decreasing peaks of current. It might be thought that a jar would be felt in the car when the field is thus weakened in one step, but this is not so. The acceleration is very smooth. Note also the overlapping of the armature current, showing the dynamic brake slowing the motor down before power is applied in the reverse direction. This is due to the time element of the switches and the electrical interlock. It is possible to add a second interlock which will make it impossible to reverse until the motor has come to rest. The ability to reverse quickly is always preferred by the owner as it saves time.



CURVE No. 3

Curve No. 3 was taken from the same elevator to show the variation of the time taken to accelerate with the load. Curve *A B* is hoisting a fair load. The elevator was then slowed to normal speed and then stopped. Curve *C D* is lowering a heavy load. Note that current is being returned to the line when the elevator is running at maximum speed. Curve *E F* is hoisting a very heavy load.

FIG. 2

Curves 1, 2 and 3 were taken from a 30-h.p. 230-volt worm gear traction elevator running at 350 ft. per min.

Dash pot timing of the acceleration also gives satisfactory results. Fig. 2 shows a controller with dash-pot acceleration, and Diagram No. 3 shows the general control circuit connections. In general the scheme of connections is the same as for Diagram No. 2. The performance of such an elevator is shown by Curves No. 4 and 5. This was a worm gear drum machine operating at 350 ft. per min. and driven by a 25-h.p. 220-volt motor having a speed range by field control from 525 to 850 rev. per min. This controller gave two speeds only, normal and maximum. The dynamic brake was applied only in the " off " position to assist the mechanical brake. Referring to Curve No. 4, curve *A B* shows acceleration of a fair load, current peak *C* shows acceleration from rest to normal speed of a heavier load. The increasing starting current with constant time of acceleration may be noted. Current peak *D* occurs as the field is weakened to accelerate to maximum speed. The car switch was then thrown back to normal speed, giving current dip *E*, and then to the " off " position. The elevator was then reversed to lower the heavy load. Current peak *F* is accelerating to normal speed, and *G* accelerating to maximum speed. The elevator was then slowed down to normal speed, giving current peak *H*. Note that current is being returned to the line. Throwing the switch to the " off " position gives the dynamic brake peak *K*. Curve No. 5 was taken from the same machine to show operation under various loads. Curve *A B* is hoisting a heavy load, curve *C D* is lowering a heavy load. The motor was then " plugged ". The retarding effect of the dash pot permits the motor to come nearly to rest before power is applied in the reverse direction. The electrical interlock between the starter and the main switch prevents this switch from closing until the starting resistance is included in the armature circuit.

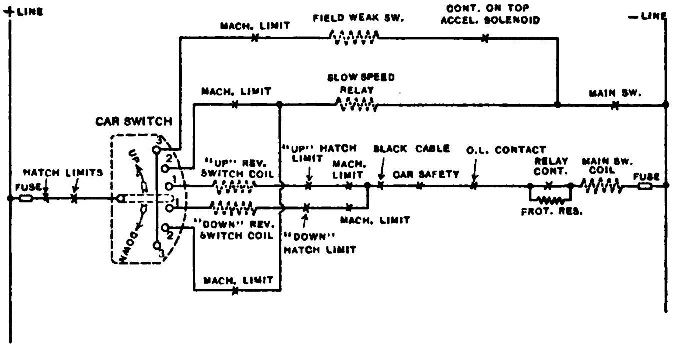
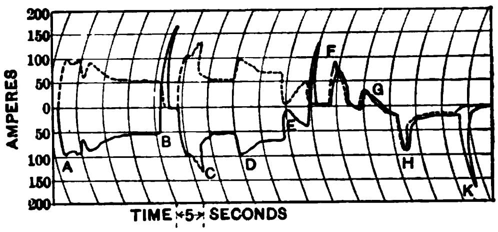


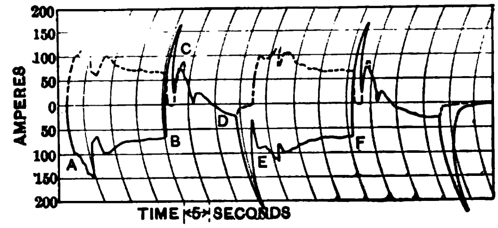
DIAGRAM No. 3

There are often cases where an elevator must lift a very heavy load once in a while, but ordinarily is required to lift much lighter loads. In some cases an elevator handles both freight and passengers. It is here desirable that the elevator operate at a fairly high speed when carrying passengers or light freight. The worm gear elevator with an adjustable speed motor having a 2 to 1 speed range, fits in here very well. Such a motor will develop its rated out-put at its normal speed as well as at its maximum speed, and will lift double the normal load at half speed safely and satisfactorily.



Curve No. 4

As noted before, however, the armature starting resistance is proportioned for normal duty to the reduced horse power output at normal speed. When a heavy load is to be lifted a switch on the controller board is closed, which connects a section of resistance in parallel with each step of the regular resistance, and at the same time opens the control circuit to the field weakening switch. This arrangement gives the necessary current inrush to start the heavy load, and makes it possible to lower this heavy load safely.



Curve No. 5

Such a controller is shown in Fig. 3. The double-pole switch is the switch connecting in the extra starting resistance. This is a worm gear traction elevator running at a maximum speed of 400 ft. per min., and driven by a 25-h.p. 220-volt adjustable speed motor having a 2 to 1 speed range. This elevator is in an 18-story office building. It is used for freight ordinarily but carries passengers at night when the other elevators are shut down. The performance of this elevator is shown by Curve No. 6. Curve *A B C* is going down light, showing the load of hoisting the counterweight. Peak *D* occurs when slowing down to normal speed. Peak *E* is the dynamic brake current when controller is thrown off. Curve *F G* is hoisting a light load. Curve *H K L* was taken when hoisting a safe, with the special switch closed. *H* is the starting current and *K* the running current. With such a heavy load the friction of rest is high, requiring a heavy starting current. Peaks *L* and *M* occurred as the elevator was slowed down and stopped.

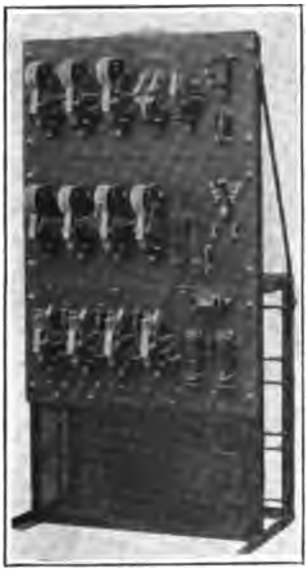
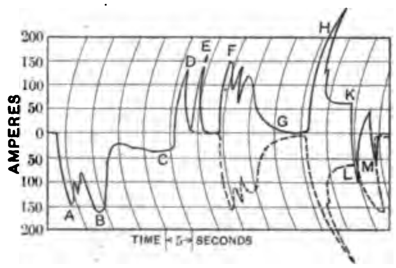
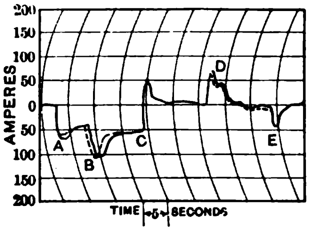


Fig. 3



Curve No. 6



Curve No. 7

As shown in the connection diagrams, the shunt field of the motor is partially excited when the elevator is at rest. This arrangement gives a quicker start than is the case when the field circuit is opened, and results in a saving of both time and energy. A test was made on an elevator to show this. The motor was 20 h.p., 220 volts, having 15 per cent compounding while accelerating, and 2 to 1 speed range by shunt field control. The elevator had a maximum speed of 350 ft. per min. The results of this test are shown in Curve No. 7. The full line shows the armature current and time required to accelerate from rest with the shunt field circuit broken in the off position; while the dotted line shows the current and time under the same load conditions when the field is partially energized in the " off " position.

A careful measurement of the original curves shows that when accelerating a heavy load, it requires 4/5 of a second longer to get under way, with an average load about 3/5 of a second longer, and with a light load 2/5 of a second longer. Curve *A B C* was taken hoisting a heavy load, and curve *D E* lowering a heavy load, thus showing the two extremes.

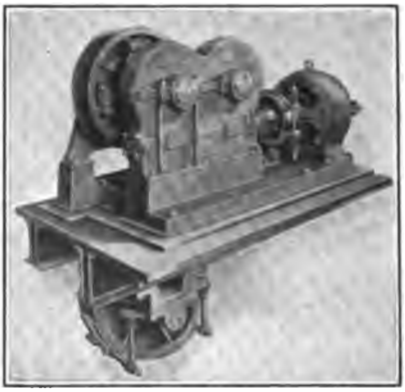


FIG. 4

When partially energized, the field takes 1.4 amperes at 220 volts, and consumes power at the rate of 308 watts. This is sometimes considered a waste of energy. Taking the average extension of the accelerating period as 3/5 second, and the starting current under these conditions as 65 amperes, the extra energy consumed during one start is 143 watt-minutes. This is as much energy as the shunt field consumes with the elevator at rest for a period of 28 seconds, or nearly half a minute. This elevator was in a 10-story building and outside of the busy period would sometimes make as few as two stops each way during one round trip. Under these conditions the trip requires one minute, and the extra energy taken at starting will make up for an idle period of two minutes. In order that there should be any saving of energy by opening the field circuit the elevator would have to stand idle more than $\frac{2}{3}$ of the time. Of course, where the elevator is to stand idle for any length of time, it pays to open the service switch, which may be of the remote controlled type where the controller is at the top of the hatchway.

The usual arrangement of the worm gear machine is shown in Fig. 4. The gears are spiral gears and intermesh so that both worms drive the one sheave. An idler sheave is mounted below the driving sheave, and each hoisting cable passes first over the driving sheave, one half turn, then under the idler, and again one half turn over the driving sheave and down to the counterweight. Each cable thus makes one complete turn around the driving sheave, which gives the necessary traction.

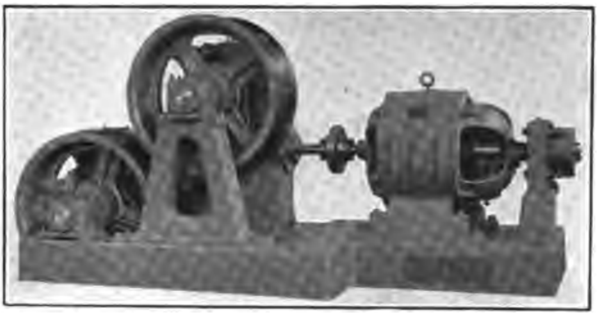


FIG. 5

Fig. 5 shows a very interesting arrangement whereby the motor drives both sheaves. The gears do not intermesh, as the thrust is taken up by the system of roping. The traction thus obtained is very high. Fig. 6 shows another view of the motor and disk brake of this machine, and the general arrangement of the controller boards. The motors have a speed range by field control from 300 to 825 rev. per min. There are three of these elevators serving an 18-story building and having a maximum speed 400 ft. per min. Owing to the wide speed range the change of speed from normal to maximum is made in two steps. As before, a speed of 25 per cent of the normal is obtained, thus giving the operator a speed control range of 11 to 1. These elevators are very busy all day and stop at all floors.

The gearless traction elevator is very generally used for large office buildings. Fig. 7 and Fig. 8 show one of these machines and the corresponding controller board. It will be noted that the machine is very simple, although it is mostly all motor, and that the controller board is more complicated than those for the geared machines. That this must be so will be seen from a consideration of what the controller must do.

This machine is driven by a slow-speed motor, 35 h.p. at 230 volts, having a normal speed of 43 rev. per min., and a maximum speed of 55 rev. per min. This is a comparatively narrow range. The maximum speed of the motor is limited by the consideration that the diameter of the hoisting sheave should not be less than about 38 inches on account of the hoisting cables. The maximum speed of this elevator is 550 ft. per min., and the normal speed 430 ft. per min. The controller must then be capable of reducing the elevator speed to about 15 per cent of the normal speed with any load in the car. This is done by a combination of resistance in series with the armature, and resistance in shunt to the armature.

FIG. 6

Diagram No. 4 shows the main motor circuits of this elevator. The general scheme is the same as for diagram No. 1, with the addition of several switches to control the armature shunt resistance. Five speeds are provided for the operator in the car,

Fig. 7

Fig. 8

the maximum speed, the normal speed, and three slow speeds obtained by dynamic brake switches 1, 2 and 3. The 4th dynamic brake switch is used in connection with the limit switches for varying the dynamic brake effect with the load in the car. It will be seen readily that the electrical efficiency of this equipment is low at the slow speeds.

Dynamic brake switches 1 and 2 are closed with power from the line, while switches 3 and 4 are connected to the armature terminals and their closure depends upon the counter-electromotive force. Position No. 5 of the car switch gives the maximum speed with weakened shunt field; position No. 4 gives the normal speed with full field; position No. 3 gives the third slow-speed with all the armature resistance in circuit and dynamic brake switch No. 1 closed; and position No. 2 of the car switch gives the second slow speed by closing dynamic brake switch 2. In this second position the coil of dynamic brake switch 4 is also connected to the armature terminals. If now the speed of the motor should be high, as when lowering a heavy load, the voltage at the motor terminals will be sufficient to close *D B* switch 4, thus automatically reducing the shunt resistance to regulate this slow speed. Position No. 1 of the car switch connects *D B* switch 3 to the armature terminals, and the closure of this switch also depends upon the load. In hoisting a heavy load *D B* switches 3 and 4 will not close as the speed of the elevator

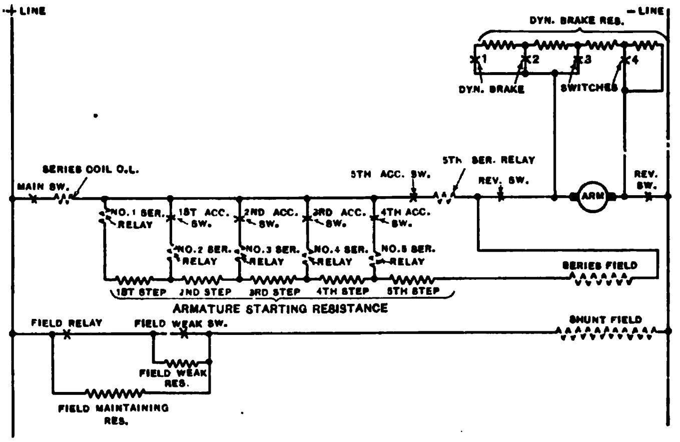
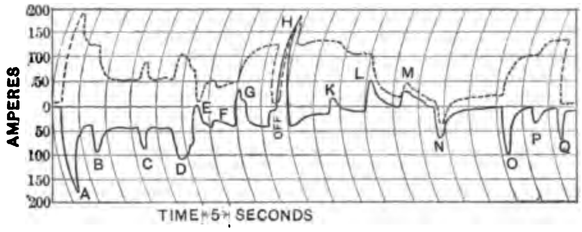


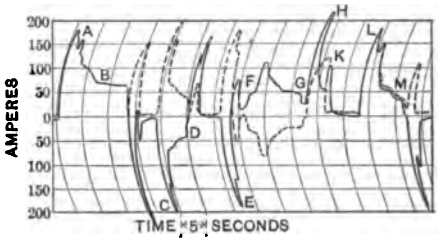
DIAGRAM NO. 4

will be sufficiently slow without them. With an average load switch 3 will close but switch 4 will not; while with a light or negative load both 3 and 4 will close. This automatic adjustment of the armature shunt resistance is necessary in order that the car may be stopped positively and accurately at the upper and lower landings by the limit switches, regardless of the load in the car; and is also of assistance to the operator in making the intermediate landings accurately. This is of considerable importance since any time wasted in bringing the car to rest at a floor means a reduction in the capacity of the elevator.



Curve No. 8

Curves No. 8 and 9 will show something of the performance of this elevator equipment. In Curve 8 the car switch was first thrown to the maximum speed position step by step, the elevator going down empty. Peak *A* is the starting current. The operator apparently passed almost immediately to the second point, and the running current is that taken in the second slow speed position. Note here that the armature current is 37 amperes, while the line current is 123 amperes. However, of this latter value the shunt field is taking 12 amperes, and additional current is taken by the brake magnet and the solenoid switches of the controller. Current peak *B* occurs when passing to the third

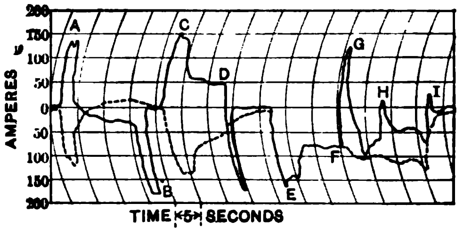


Curve No. 9

slow speed, *C* when passing to normal speed, and *D* when passing to the maximum speed. The elevator was then slowed down gradually. Current dip *E* occurs when passing to normal speed, and *F* and *G* show 2 of the slow speeds.

The elevator was then reversed and the car switch manipulated in the same manner. Peak *H* is the starting current going up light. Note that on the two slow speed points showing, the armature is generating some current, but that a heavy current is still being taken from the line. Peak *L* is accelerating to normal and *M* to maximum speed. *N* is slowing down to normal speed, and *O*, *P* and *Q* are the three slow speeds.

Curve 9 shows something of the regular service conditions. Curve *A B* is hoisting a heavy load, *C D* lowering an average load. Beginning at *E*, the curve shows the start and run, and then the slowing down and stopping of a very heavy load. Note that for the part *F G*, a heavy current is sent back to the line. *L M* is hoisting the average load.

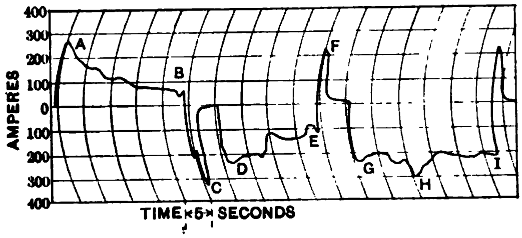


Curve No. 10

Curve No. 10 shows the performance of gearless traction elevator controller having the counter e.m.f. system of acceleration where the armature resistance is cut out as the counter e.m.f. rises. As before, the slow speeds are obtained by shunting the armature. *A* is going down with a load, and *B* is the braking current, *C D* is going down light. *E F* is hoisting a heavy load, and peaks *G*, *H* and *I* show the current when slowing down gradually. As a basis of comparison the elevator of curves 8 and 9 has a capacity of 18 passengers at 550 ft. per min., while the elevator of curve 10 has a capacity of 12 passengers at 550 ft. per min. The motors have the same rating and about the same maximum speed, but I do not know the speed range by field control of the motor of curve 10.

Comparing the two systems of acceleration, the counter e.m.f. system is affected by line voltage variation much more than is the series relay system. In the series relay controller the adjustment of the relays is independent of the line voltage, and as the switches will function at any voltage from normal to 20 per cent below or to 20 per cent above, the motor will be accelerated at any voltage within this range with the same current value. In the counter e.m.f. system, the accelerating current will vary greatly with the line voltage, reaching an objectionably high value if the voltage is high; or falling so low with a low voltage that the starting resistance may not be cut out, or the time for acceleration becomes objectionably long. If the line voltage is constant, the two systems will give the same results.

Dash pot control of the acceleration gives a constant time for the cutting out of the armature resistance, which results in a slower start at light loads, and a high starting current at heavy loads. With a motor of proper size and character the dash pot system may be made to give results as satisfactory as with the other systems. However, the tendency in this system is to make the accelerating period longer than with the other two. Curve No. 11 shows an exaggerated case. This is a special elevator running at 575 ft. per min., and driven by a 30-h.p. 115-volt moderate speed motor. There was no speed control by field variation, but the acceleration was controlled entirely by armature resistance. There were no slow speeds, but a dynamic brake was applied in the " off " position to assist the mechanical brake. Curve *A B* is going down light, showing the load of hoisting the counterweight. Current peak *C* is the dynamic brake. Curve *D E* is hoisting an average load and peak *F* is the corresponding dynamic brake current. Curve *G H I* is hoisting a heavy load, the part *G H* being the accelerating current with an accelerating period of about 10 seconds. This long time is of course neces-



CURVE No. 11

sary where the starting current exceeds the running current by such a small margin.

The energy required to run an elevator depends upon the service rendered, so that in many ways the power consumption basis of comparison is unsatisfactory. The following results of a test of a gearless traction elevator will show this. Running the empty car, but stopping at every floor both ways required 6.4 kw-hr. per car-mile. Running the car with maximum load and stopping at all floors required 10.4 kw-hr. per car-mile. Running with ⅔ load, but stopping top and bottom only, required but 2.4 kw-hr. per car mile. Stopping at all landings with ⅔ load required 8.8 kw-hr. per car-mile.

In a 22-story office building equipped with gearless traction machines the express elevators serve the 10th floor and above, and run at 600 ft. per min. They make about 22 miles per day with a power consumption of 3.5 kw-hr. per car-mile. In the same building the local elevators, serving the first to tenth floors, run at 400 ft. per min., and make about 9 miles per day with a power consumption of 4 kw-hr. per car-mile.

The gearless machines of Figs. 7 and 8 serve an 18-story office building, making all floors, and require 3.44 kw-hr. per car-mile. In the same building the worm gear traction elevator whose controller is shown in Fig. 3 and performance by curve No. 6 require 3.58 kw-hr. per car-mile.

The worm gear elevators of Figs. 5 and 6 serve an 18-story office building stopping at all floors, and make an average of 21.8 miles per day with a power consumption of 3.28 kw-hr. per car-mile. The elevators similar to that of Fig. 4 serve a 13-story building, running at 400 ft. per min. They make about 19 miles per day with a power consumption of 3.88 kw-hr. per car-mile.

A worm geared drum machine having a controller like that of Fig. 1, makes 12.9 miles per day, at a maximum speed of 240 ft. per min. The average consumption of energy per car-mile is 2.76 kw-hr. The average of a number of worm-gear elevators. each having a maximum speed of 400 ft. per min., give a power consumptionof 3.8 kw-hr. per car-mile. An average of the gearless elevators running at 550 ft. per min. gives 3.5 kw-hr. per car-mile.

On the side of mechanical simplicity and efficiency the gearless machine has the advantage. The motor at maximum speed and 75 per cent load has an efficiency of 80 per cent, and at normal speed and 75 per cent load an efficiency of 67 per cent. At half load, which is nearer the average condition, the efficiency is 58 per cent at normal speed and 76 per cent at maximum speed. Also as noted above the electrical efficiency is greatly reduced where the elevator is operated at the slow speeds. The controller is more complicated but not less reliable, and the necessary elements for security are readily provided. The mechanical arrangements also facilitate smoothness of operation, which is a very desirable feature.

In the geared machine the mechanical efficiency is lower, but this introduces a factor tending towards greater security; there is a reduced tendency to run away. The moderate speed motor of this machine has an efficiency at half load of 90 per cent at maximum speed, and 78 per cent at a normal speed one half the maximum. At 75 per cent load the efficiency is 91 per cent at maximum speed and 81 per cent at normal speed. This increased motor efficiency will nearly make up for the reduced mechanical efficiency at maximum speed, and at one half speed will more than make up for it.

DISCUSSION ON "ELEVATOR CONTROL." CHICAGO, JUNE 28, 1911.

Fred J. Newman: I want to ask the author of the paper what is considered high efficiency for worm gearing, also what the characteristics of the efficiency curve would be in regard to speed and tooth pressure. What would be the increased efficiency by use of ball bearings for end thrust?

S. N. Clarkson: Most central stations have a limited direct current area, and the tendency is for large office buildings to extend beyond the area of direct current distribution. It would be very interesting therefore to hear Mr. Barnum's experience with alternating current elevators, both with the wound rotor type motors and the squirrel cage motor with starting torque approximately equal to the pull out torque.

Theodore Varney: I wish to ask a few questions with reference to Mr. Barnum's paper. I think one of the speakers made an inquiry in regard to suitable controllers for alternating current elevator motors, I wish to ask Mr. Barnum if he has had success with such controllers for the higher speeds?

Referring again to Mr. Barnum's paper, I would inquire whether the slow speed points, where he uses a resistance in series with the armature and a shunt resistance around the armature, are entirely hand controlled, or whether he uses automatic relays for regulating the slow down, and if so, whether these relays are adjusted to the load on the motor at the time?

T. E. Barnum: I have no figures on tooth pressure, and very little data on the efficiency of worm gears. On one machine where a single worm and gear is used, with a ball thrust bearing, the efficiency from the motor to the load is about 75 per cent. With a standard worm gearing and collar thrust bearing on an overhead traction machine, the efficiency would be about 60 to 65 per cent. There are, of course, many factors of general design entering that would modify the conditions of operation and the efficiency.

Regarding the saving of energy, it is desirable to open the shunt field circuit if the elevator is to stand idle for any length of time. Where it is inconvenient for the operator to go to the service switch, it is possible to arrange very simply for the remote control of the main line switch. This arrangement is desirable in many cases where the machine and controller are at the top of the hatchway, and the operator leaves the car at the bottom landing.

The paper gives some information regarding the possible saving of energy under operating conditions when the shunt field circuit is partially excited in the "off" position of the controller.

The subject of alternating current elevators is a large one and it is difficult to answer briefly. I do not know of any high speed alternating current elevators. The principal difficulty in the way of a high speed alternating current elevator is that it is not possible with the present commercial polyphase motors to obtain speed control regardless of load. For this reason the elevator must be stopped by the mechanical brake alone, and this device is very unsatisfactory where the speed is high. The high speed alternating current elevator will not be satisfactory until we can get, with the polyphase motor, the equivalent of the field control and dynamic brake of the direct current motor. As far as acceleration is concerned, the alternating current motor will give as satisfactory results as the direct current motor, provided that the alternating current motor rating is not pushed up so far that the starting torque is close to the break down torque.

Answering the other question about slow speed, the control of this speed is manual by the operator from the car switch. With the worm gear machine there is no automatic adjustment of the armature shunting resistance, although the closure of the armature shunt circuit depends upon the counter electromotive force. With very high speed gearless machines, there is an arrangement described in the paper for the adjustment of the slow speed resistance to take account of some variations of load in the car. This automatic adjustment is necessary on high speed elevators in order to be able to set the limit switches so as to stop the car at the end landing with maximum load, and also have a satisfactory stop at light loads.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

ELECTRICALLY DRIVEN REVERSING ROLLING MILLS

BY WILFRED SYKES

The load conditions under which motors driving continuous running rolling mills operate is generally understood, and the advantage to be obtained by using a suitably designed flywheel is well known. Owing to the rapidly fluctuating load, some system of energy storage capable of performing a large amount of work for short periods must obviously be of considerable value not only from the standpoint of motor operation but also from that of power supply. Several papers have been read before this Institute dealing with the question of the action of flywheels with such loads and the advantage has been clearly demonstrated. The value of flywheels can be best appreciated when used with mills with very high and short peak loads, such as a blooming mill, where loads up to 10,000 h.p. for one or two seconds are not infrequent. The antithesis of this type of mill is the reversing mill where every effort is made to reduce the flywheel effect to a minimum so that the accelerating force required may be kept within reasonable limits. Most engineers connected with industrial work are familiar with the development of electrically driven continuous running mills but the development of the reversing mill is not generally appreciated except by those more or less connected with their design and operation. The object of this paper is to briefly review some of the more important points in its design and operation.

The application of electricity to reversing rolling mills is one of the most important technical advancements in industrial engineering that has been made during the last ten years and it is of considerable commercial importance as the value of the equipments already supplied or on order amounts to approximately ten million dollars.

Previous to 1905 the engineers of some of the large European electric manufacturing companies had given the reversing mill considerable attention. A study of the problem showed that in order to have a feasible arrangement some provision would have to be made to equalize the input to the plant as no generating station of moderate size could take care of the rapid fluctuations of load which occur with this class of mill. Furthermore, the question of controlling the large motors necessary for this work was given a great deal of consideration and the conclusion arrived at, that the ideal arrangement for such a plant was the Ilgner system, such as had been previously applied for large hoisting equipments. This system, as is generally known, provides for the equalization of the load and also for the control of the operating motor. The motor is of the direct-current type, generally shunt type, supplied with power by a special generator which is in turn driven by a suitable motor. The motor-generator set is connected to the flywheel and means are provided for automatically varying the speed of the set depending upon the load. The operating motor is constantly excited and the speed is controlled by varying the voltage supplied to the armature; the voltage being varied by means of a regulator in the generator field. To reverse the motor the generator field is reversed. This control is extremely simple as only the shunt current of the generator is handled. The automatic regulator for the motor generator set is so arranged that when the load on the set exceeds the average value the speed of the set is reduced and the flywheel gives up part of the energy stored in it, thereby assisting the motor to drive the generator and eliminating the peak loads on the generating plant. During periods of light loads the flywheel is accelerated and by properly designing the equipment the input can be maintained fairly constant.

In 1903 experiments were carried out to determine the possibility of operating a motor under such conditions as are met with in reversing rolling mills. For this purpose an electric hoist of the Ilgner type was selected, the rope being removed from the drum and the motor and drum reversed as rapidly as possible. These experiments demonstrated that it was quite possible to operate suitably designed machines under the severe conditions to be met with, but at that time no steel mill owner could be found willing to try the experiment. About the same time

MATERIAL

No.	Purchaser	Type of mill	Finished material	Weight tons	Origin. cross section
1	Oesterr. Berg-u. Huettenwerks - Gesellschaft, Teschen. Eisenwerk Trzynietz. Hildegardehuette	Rail Mill 4 stands	Rails to 70# Girders to 17½" Billets to 2"□	Max. 2	15"□
2	Priv. K. K. oesterrungar. Staatseisenbahn - Gesellschaft for the works in Resicza.	Rail Mill 4 stands	Rails to 70# Girders to 19½"	Max. 1.6	10½"ø
		Blooming mill 1 stand	Billets 2"□	Max. 3.5	23½"x1
3	Illinois Steel Co.	Universal plate mill	Plates	2.5	7"x30
4	Same as No. 2.	Plate mill 1 stand	Plates 110" wide ¾" thick	3.5	Max 15½"x3
		Universal Plate mill	Plates 39" wide ¾" thick	3.5	15½"x30
5	Grillo, Funke & Co., Gelsenkirchen.	Tube mill	Corrugated pipes		
6	Rombacher Huetten-werke, Rombach.	Billet mill 2 stands	Billets to 2"□ and ties	2.85	8½"x7"
7	Georgs - Marien - Berg - werks - u. Huettenverein, Osnabrueck.	Blooming mill 1 stand	Blooms	2.5 to 5	15½"□ to 21½"x2.
8	Georg Zugmayer & Söhne, Waldegg Nieder - Oesterreich.	Copper mill 1 stand	Copper sheets	3	63"x6
9	Rhein. Stahlwerke, Duisburg-Meiderich.	Blooming mill 1 stand	Blooms	2.5 to 3.5	19"□
10	Dorman Long u. Co. Ltd Cleveland, Wire Works, Middlesbrough.	Girder and rail mill 2 stands	Angle iron 3"x3" Girders to 6" light rails	0.35	6"□ and 3"□
11	Huestener Gewerkschaft A-G. Huesten.	Slabs 3 stands	Slabs 14"x¾" billets 2"□	1.4	15½"□ to 13½"□
12	Aciéries et Forges de Firminy, Firminy.	Blooming mill 5 stands	Billets 2"□	0.5	12"□
		Armor plate mill 1 stand	Slabs 20"x¾" armor plates 30"x90"x8"		
13	Mansfeldsche Kupferschieferbauende Gewerkschaft Eisleben, Kupfer u. Messingwerk, Hettstedt.	Sheet mill 1 stand	Plates and sheets	2.0 to 5.0	61"x8
14	Oberschl. Eisen - Industrie Gesellsch. Gleiwitz Julienhuette	Blooming mill	Blooms and billets 3" & 2"□	4.5	22"□
15	Koenigl Ungar. Eisen & Stahlwerke, Diosgyör.	Blooming mill 1 stand	Blooms	3.0	21½"□
		Rail mill 3 stands	Rail and profiles	1.5	21½ sq
16	Witkowitzer Bergbau u. Eisenhuetten gewerkschaft Witkowitz	Armor plate mill 1 stand	Armor plates	80	98"x38
		Sheet mill 1 stand	Sheets	10	47"x20
17	Rhein. Bergbau und Huettenwesen A-G. Niederrhein Hütte Duisburg-Hochfeld.	Blooming mill 1 stand Finishing train 1 stand	Slabs and billets, later rails and girders	2 to 5	19"x11

TABLE I.—Continued

			ROLLS				
Elongation	No. of passes	Capacity of mill tons per hour	Diameter inches	Speed of rolls r.p.m.	Drive from motor	No. of motors	Voltage across each armature
8.7	13	68	43	±120	direct	2	630
16.7	1	55					
4	13	45	36	±120	direct	2	550
30	20	35	32				
31	21	35	33				
10.5	9	24	29½	±180	direct	2	600
8.3	9	40					
8	9	39	34½	±180	direct	2	900
5.1	11	54					
14	17	50	47½	±45 to ±65	direct	1	900
	7	20	32	±20	direct	2	230
5.65	15	75	32	±75	direct	2	
			35½ to 44½	±40 to ±55	direct	1	1100
12	9	30	29½	±180	direct	2	580
6.5	11	45					
9.5	9	32	35½	±150	direct	2	630
4.2	11	65					
12	8	90	19½	±180	gear		
25	25	50	45½	±100	direct	2	610
47 18 to 33	42	23.50	44½ to 43½	±54 to ±90	direct	1	1330
7.2	15	70	43½	±120	direct	2	600
				±350		1	440
			22	0 to 120	direct	1	440
10	10	40	41½	±75	direct	2	600
Max. 40		40	37½	±130	direct	1	1000
			49 diam.	±90	direct	2	

experiments were also carried out on steam driven reversing mills to determine the power requirements and information was obtained which enabled the electrical engineers carrying out this work to determine more or less exactly the power required under various conditions. It is interesting to note that one of the earliest reversing mills installed gave results corresponding very closely to the figures worked out in 1903.

It was not until 1905 that a mill owner could be found willing to install an important drive of this kind, in view of the fact that nothing of a similar nature could be shown. At last the Oestreichische Berg und Huttenwerke Gesellschaft, Austria decided to try the experiment when remodeling its works at Trzynietz and after a considerable time had been spent in investigating the power requirements of its then existing steam driven mill an order was placed towards the end of 1905 and the plant started in July 1906. This plant was rated to have a maximum capacity of 10,350 h.p. but since it has been in operation the load has often exceeded this value. The results achieved with this initial installation encouraged other companies to install this type of mill and the attached table shows the mills that are in operation or ordered up to the end of February of this year. It will be seen that at the present time 32 mills of this type have been installed or ordered in Europe and three in this country.

This table shows the great range of material that is handled by this class of mill and the large capacity of some of the plants. The ratings of the roll motors are the loads that are regularly met with during rolling but these values are often exceeded especially when rolling comparatively cool material. The difference between the size of the generators and the driving motors is explained by the fact that the former handle all the current peaks, and the heating being proportional to the square of the current, the generator must be much larger than the motor which carries only the average load.

Fig. 1 shows graphically the development of this type of mill and it will be seen that during the last year the business secured has rapidly increased. In view of the technical difficulties in building mills of this kind and of the high first cost, it may be asked why reversing mills are used at all, as in a general way it may be said that three-high continuously running mills can do the same work, the construction of this kind of mill representing no particular difficulties and being comparatively cheap. The following are the principal reasons for using reversing mills.

1. Where the mill has to roll a large number of different sections and operates only for a short time on one particular class of work. This means frequent changing of rolls and the two-high mill is very much more convenient in this respect than a three-high mill, the cost of rolls being considerably reduced and also the time required for making the change.

2. The economy of the reversing mill with intermittent work is higher than that of the continuous running mills, principally on account of the elimination of friction load when the mill is not in operation. The friction load is often a very appreciable fraction of the total work and is, of course, particularly noticeable where the mill is working at a small percentage of its normal capacity. With a three-high mill this loss is going on continuously, whereas the reversing mill is at rest and the only losses are those in the motor generator set which are generally less than those due to the mill friction. The auxiliary equipment of the reversing mill is somewhat simpler than that of the three-high mill, the lifting or tilting table being eliminated. The balancing arrangement of the rolls is also simpler as only one roll is moved.

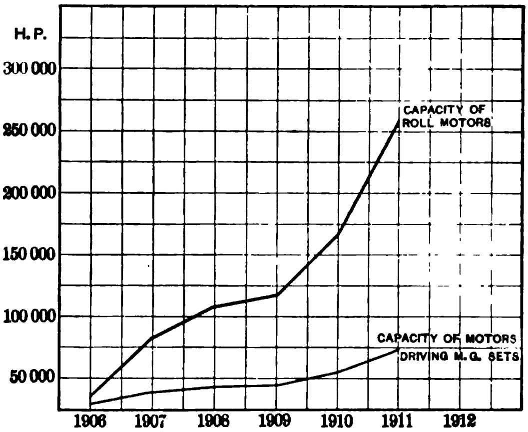


FIG. 1.—Curve showing the capacity of reversing rolling mills, installed or under construction

Fig. 2 shows graphically some results based upon tests carried out in Europe, which show the superiority of the reversing mill when on light loads. These curves are based on rolling three-ton ingots to various sections, the elongation varying from 5 to 10; and it will be seen that on light loads the efficiency of the three-high mill, on account of the friction losses, is considerably less than that of the reversing mill, while at full load both types show about the same results. In works where the rolling is irregular, the reversing mill can show an appreciable saving besides the other advantages incidental to this type. The curves have been made up from actual test results and if anything, they favor the three-high mill, as the friction taken is not the highest obtained. The efficiency of the motor has been taken high and generally under working conditions it would be about 5 per cent less at full load on account of the slip resistance in the rotor. At light load the efficiency would not be appreciably affected by this extra resistance. In smaller works there is likely to be a greater variation in the production than with larger

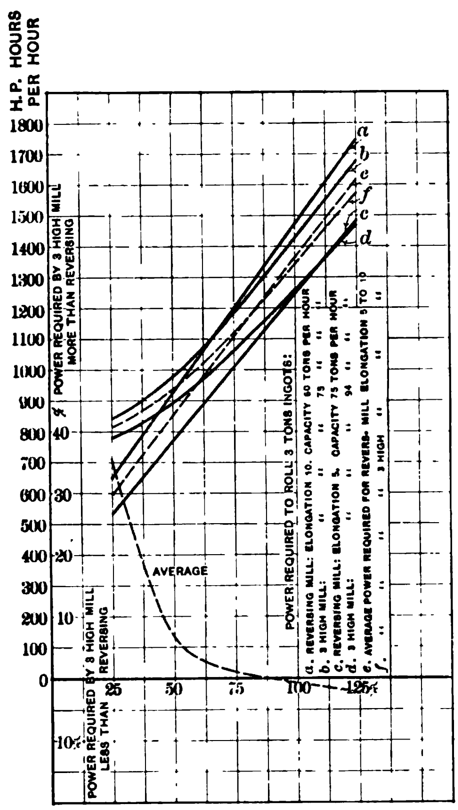


FIG. 2.—Curve showing the relation between the power required for reversing and three-high mills for various outputs

concerns and this is to a certain extent the reason why the reversing mill has made greater progress in Europe than in this country as the competition for orders is greater and a greater variety of work is being handled. The production of the three-high mill is somewhat greater than the reversing mill but it is gained by a greater complication of the mill itself although the driving equipment is much simpler. It must be born in mind, however, that the upkeep of the mill is very much greater than that of the electrical equipment so that the extra complication of the reversing mill drive does not offset that of the three-high mill over the two-high. As an indication of the capacity of electrically driven mills, the following figures obtained in operation from the plant at Rombachhutte may be of interest:

67 tons, 2 in. sq. billets per hour, elongation........11.5
83 " 2⅜ " " " " 9.86
105 " 3¼ " " " " 5.3

Control of Roll Motors

Reference has been made to the method originally adopted of controlling the reversing motors by regulating the generator field and this system has been universally used for all installations at the present time with one exception. For large motors of eight or ten thousand horse power it is obvious that any system of rheostatic control would not be feasible and a voltage control system is the only one that can be considered. In the case of smaller plants of one or two thousand horse power there has been some discussion as to whether the rheostatic system of control is possible or not. Leaving aside the question as to the possibility of designing a reliable rheostatic control for such work, it might be well to consider the operation of such an equipment. One of the outstanding features is the maneuvering capacity of plants with the voltage control system as the speed of the motor corresponds to the position of the controller handle and any amount of braking that is necessary can be obtained without any difficulty. A very important feature, however, is the power required for accelerating the motors. With the voltage control system approximately 40 per cent to 50 per cent of the accelerating power is lost in various transformations that take place, that is to say, 50 per cent to 60 per cent of the input of one acceleration is available for accelerating the motor the second time after allowing for all losses. The voltage control system, of course, has no rheostatic losses, consequently the total input is the same as the energy stored in the moving masses. With the rheostatic system of control only one-half of the energy taken from the line is available for accelerating the motor and none is recovered. To illustrate this point the following example can be taken. In rolling 2 in. square (25.8-sq. cm.) billets from 15 by 15 by 45-in. (38 by 38 by 114 cm.) ingots in 19 passes the actual work put into the rolls was 141,740 h.p.-seconds, the total energy required for accelerating the motor was 30,543 h.p-seconds but as a portion of this was recovered, the actual horse power required for accelerating was approximately 18,000 h.p-seconds. With rheostatic control the input to the line would have been twice as much as with the voltage control of 61,086 h.p-seconds, which is approximately 43 per cent of the useful work, whereas with the voltage control the loss corresponds to about 12.7 per cent of the useful work. This difference in power consumption is of considerable importance and will at the end of the year represent an appreciable increase in the total input.

Another feature which has been raised is the quickness of operation, it being claimed that the rheostatic control enables the motor to be reversed more quickly than is possible with voltage control on account of the magnetic lag of the generator field with the latter system. This feature is, from an operating standpoint, of no particular value, as experience has demonstrated that the mill can be reversed as quickly as the material can be handled, and quickness of operation is not the limiting feature in the output of the mill. It might be mentioned that a test of two motors having a maximum total rating of 7,000 h.p. showed that they could be brought to a speed of 60 rev. per min. 28 times per minute, and another mill with motors having a rating of 10,000 h.p., a speed of 100 rev. per min., was reached 14 times per minute. In the latter case the energy stored in the moving masses was approximately four times as great as in the former case. The universal experience has been that motors with voltage control can be operated as quickly as the material can be handled, and considerably quicker than a steam-driven reversing mill.

Several methods are used in practice to obtain quick operation with the voltage control system. One method is to indirectly compound the roll motor, this being done by means of a series generator the field of which is excited by the armature current of the motor. The current in the winding excited by this generator is comparatively small and is easily reversed by the controller, whereas any system of direct compounding would necessitate operating a switching device capable of handling several thousand amperes, which would be hardly practical. With this arrangement the time required to accelerate the roll motor is shortened as the torque available for a certain armature current is greater on account of the stronger field, the difference depending however on the saturation of the field. This arrangement has the advantage that the speed of the motor will vary somewhat with the load and consequently in case of a very heavy overload part of the energy stored in the moving parts is available to assist the motor whereas with a shunt machine the speed variation is so small that all loads must be taken by the motor and generator.

Another method of increasing the rate of operation is to wind the generator fields for a comparatively low voltage and connect a large non-inductive resistance in series with them. This has been used to a considerable extent as it is simpler than the arrangement just described and it is possible to obtain just as high a rate of operation as is necessary in practice.

Various methods have been proposed, such as connecting a booster in series with the generator field, this booster being arranged so as to allow full exciter voltage on the field at starting but reducing it to that for which the field is wound as soon as the motor is running at full speed. Such schemes are, however, unnecessary for ordinary purposes.

One rather important point to be provided for in connection with the control of plants working on voltage control is the effect of the residual magnetism on the generator field. When a roll motor is at rest, the generator armature has only the resistance of the motor armature in series with it. With a very small residual field it is possible to obtain quite an appreciable current. The principal danger is that the rolls may start to slowly revolve should the current flowing be sufficient to overcome the frictional movement and in this way a serious accident may occur. A very simple way to avoid this danger is to short circuit the generator when the controller is in the off-position. Another method which is perhaps preferable is to arrange the controller so that when it is in the off-position the generator field is so connected across its armature that any voltage generated due to residual field will cause a current to flow in the shunt winding tending to kill the residual field and in this way it is possible to eliminate the current due to residual field altogether.

Slip Regulation. In connection with the motor-generator set the operation of the regulator for automatically varying the speed is of considerable importance. Various arrangements have been worked out for this purpose for use with three-phase motors, one of which has been used in this country, involving the use of magnetically operated switches which are cut in and out by means of current relays, thereby introducing more or less resistance into the rotor circuit of the driving motor. The relays for controlling these switches are arranged with two settings, one relay causing the switches to open and the other causing them to close.

FIG. 3.—Automatic liquid slip regulator for controlling the speed of flywheel motor generators

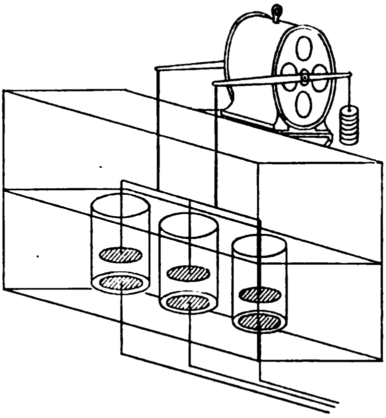


FIG. 4.—Diagrammatic sketch showing the construction of the automatic slip regulator illustrated in Fig. 3

Regulators of this type have been used for a number of years with satisfactory results but they have a number of disadvantages due to their complication which make it desirable to adopt some simpler device, such as a liquid regulator of the type described below.

Another arrangement that has been used for automatically varying the slip is the face plate rheostat operated by a small motor, this motor running continuously and clutches being provided for operating the contact arms in either one direction or the other, these clutches being controlled by suitable relays.

During the last few years the liquid slip regulator has come into use for this class of work and has given very satisfactory results. Fig. 3 illustrates a regulator of this type for controlling a three-phase motor driven set and Fig. 4 shows diagrammatically the arrangement of the same.

The moving electrodes of this regulator are operated by a small induction motor which is supplied with current through a series transformer in the primary circuit of the main motor. The torque of this motor tends to separate the plates and at normal load the motor torque plus that of the counterweight just balances the weight of the moving electrodes. If the current should tend to increase above the normal, the increased torque of the motor causes the electrodes to separate, thereby reducing the speed of the set and enabling the flywheel to give up a portion of the energy stored in it. Should the current fall below the normal value the torque of the motor decreases and the electrodes come closer together, thereby decreasing the resistance in the rotor circuit and causing the speed of the set to increase. This type of regulator has been used very successfully for reversing rolling mills and hoisting plants. As it will be seen, it is very simple and is also very sensitive.

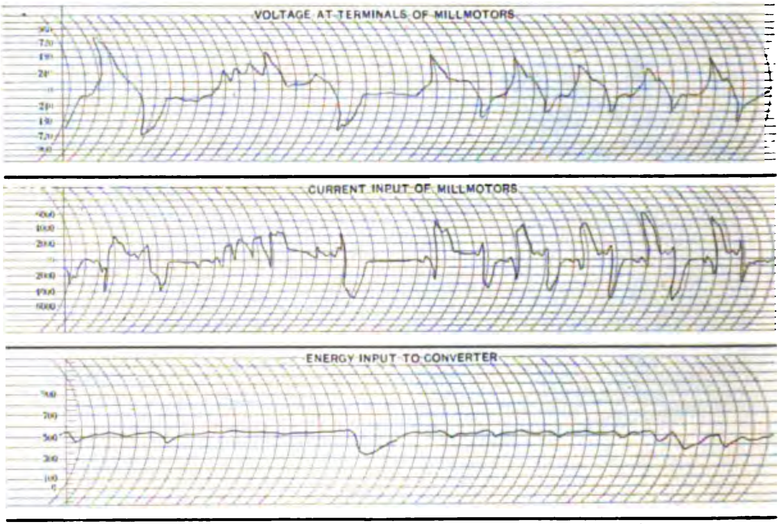


FIG. 5.—Typical curves showing the power input to a reversing mill and illustrating the operation of the slip regulator

Another type of liquid regulator used involves the same principle as the face plate regulator mentioned above, the electrodes being operated by means of a small motor which drives the moving parts through clutches, the clutches being operated by relays.

Liquid regulators have a number of advantages over any type of regulator using switches for varying the resistance in steps. They are simpler and less expensive and in operation, the type using a torque motor is much more sensitive than any arrangement with relays because the best that the latter type can accomplish is to regulate within certain limits. The liquid regulator has only been generally adopted recently as there are a number of difficulties in manufacturing this type for large capacities. Fig. 5 shows a typical test of a reversing mill from which the operation of the equalizing equipment can be seen. In spite of peak load of 3000 kw. the load on the line does not at any time exceed 550 kw.

Machines. It is obvious that to withstand the operating conditions, ordinary direct current generators and motors would not be suitable. The generator must be capable of commutating its maximum current at a small percentage of its normal field and its armature reaction must therefore be completely compensated. In the earlier machines, the Deri type of generator was used, but experience has shown that it is not necessary to go to such an expensive construction and machines are now built with interpoles with the compensating winding in the face of the main poles. In order that the machines can rapidly change their field strength, the generator fields are always laminated. The motors must, of course, be able to handle the same currents as the generator, but the condition is somewhat different, as the motor always has full field at starting and the operating speeds are much lower. As far as the motor is concerned, the principal point to be observed is to reduce the inertia of the rotating parts to a minimum. This is generally done by using as light a construction as is consistent with necessary mechanical strength, and in the case of large units using two or more machines. However, the progress that has been made in the design of reversing mill equipments is shown to some extent in the construction of the driving motors. The first plant at Hildegradhutte had three motors on the same shaft, with a total maximum rating of 10,350 h.p. The largest plant that has been installed is that at Rombachhuttee, the motors having a maximum rating of 15,000 h.p., only two machines being used. The plant which is now being built for the Acieres de Longwy à Mont St. Martin has one motor with a maximum rating of 12,800 h.p.

The motors are invariably of the interpole type, generally with compensating windings in the main pole faces, the field being usually solid with laminated poles. In a few cases, however, laminated fields have been used.

Flywheels. In Europe cast steel wheels have been used exclusively, several manufacturers having made a specialty of the construction of such wheels for high peripheral velocities. It has been possible for the steel manufacturers to do this on account of the large demands for such wheels for the Ilgner hoisting plants. In this country the demand for such wheels has not been such as to justify manufacturers specializing along these lines and consequently it is not possible to obtain large wheels for high velocities with suitable guarantees as to mechanical properties. Most of the plants using flywheels that have been built in this country, have wheels built up of steel plates. These wheels are capable of running at very high speeds without excessive stresses and they can be manufactured at approximately the same cost as cast steel wheels. The maximum size of plate that it is possible to obtain is about 11 ft. (3.35 m.) wide so that the greatest diameter of wheel that can be built up of solid plates is about 10 ft. 6 in. (3.2 m.). For slow-speed sets this does not give a peripheral velocity high enough to keep the size of the wheel within reasonable limits and it is necessary to adopt some form of wheel built up in segments. Two wheels of this type have been in use for some years at the plant of the Illinois Steel Co., these wheels consisting of a cast steel hub with a laminated rim. These wheels weigh 100,000 lb. (45,359 kg.) each and run at a peripheral velocity of 15,500 ft. (4, 724 m.) per minute. In Europe cast steel wheels are in use running at velocities up to about 22,000 ft. (7,010 m.) per minute and solid plate wheels have been supplied for a speed of 24,000 ft. (7,315 m.) per minute, some wheels having been tested by the writer up to 30,000 ft. (9,144 m.) per minute. The weight of a single wheel seldom exceeds about 50 tons on account of transportation difficulties.

Efficiency of Reversing Mill. The question as to the efficiency of reversing rolling mills has often been raised and comparisons made with steam driven units. The advantage of the reversing roll for irregular work has been shown in Fig. 2. Fig. 6 shows the efficiency of one of the latest reversing mills installed, this efficiency being the relation between the work given out by the mill motor and the input to the motor generator set. It will be noted that the efficiency when rolling hard material is a little less than when rolling soft material, this being due to the fact that the hard material requires a greater number of passes for the same reduction of area. It will be seen that at full load the efficiency of the equipment is about 65 to 70 per cent.

With a modern steam-driven plant it will be possible to generate one h.p-hour for approximately 12 lb. (5.4 kg.) of steam and allowing 5 per cent for transmission losses and 65 per cent for the efficiency of the rolling mill plant, it will be seen that the steam consumption per h.p-hour at the rolls is about 19.5 lb. (8.84 kg.).

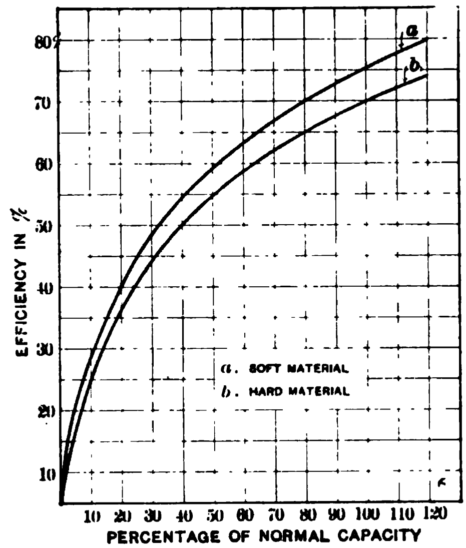


FIG. 6.—Curves showing the efficiency of a reversing rolling mill when working at various capacities

Taking the latest type of reversing mill engine with a valve between the receiver and the low presssure cylinder so as to save the steam from the high pressure cylinder when reversing, which would otherwise be exhausted to the condenser, the best figures that have been obtained are 27½ lb. (12.5 kg.) of steam per 3 h.p-hour. This is when working with 26 in. (63.4 cm.) vacuum and 90 deg. fahr. superheat.

Considering the loss due to condensation and leakage in the pipes, this figure would have to be increased to at least 30 lb. (13.6 kg.) of steam per b.h.p-hour, consequently under the most favorable conditions the steam driven reversing mill will take at least 50 per cent more steam than an electrically driven mill. The figure given for the steam consumption of a steam mill is for a modern plant of the best construction. With an ordinary plant working condensing but without superheat and with simple single valve control a recent test gave 53 lb. (24 kg.) of steam per brake horse power.

Power Requirements. The power required to drive rolling mills depends on a great many factors, among which may be mentioned the temperature of the material rolled, the profile of the finished material, the number of passes and the type of mill. In Fig. 7 some curves are shown which are the results of tests made in Europe to determine the power requirements of rolling mills. These curves show average results and are useful when used in conjunction with the efficiencies shown in Fig. 2 to determine the power input for a given output of finished material. From these curves it is possible to determine, with reasonable accuracy, the power requirements of the mill providing there are no abnormal conditions, but the figures given are only good for mills rolling blooms, billets, heavy girders and rails

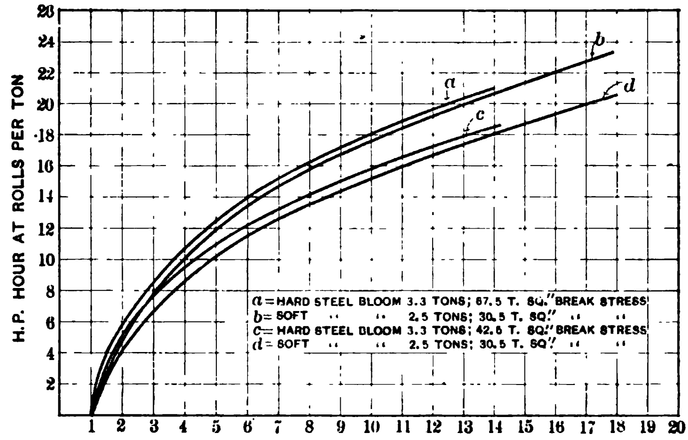


Fig. 7.—Curves showing the power required for rolling steel for various elongations

where the temperature does not drop below about 1700 deg. fahr. and the form of the finished product is simple. For angles, tees, light rails, bar iron, thin plates and sheets the power required is much greater and cannot be so simply expressed. From the curves given it is possible to determine the power required for the individual passes but in estimating the size of motor necessary many other factors must be considered. The acceleration of the moving parts and also the friction of the mill must be allowed for, and tests show that the initial peak may be considerably higher than the average during rolling, probably on account of the temperature of the end of the ingot, bloom or billet, as the case may be, being lower than the average. The curves given in Fig. 7 show the net rolling work and do not include the losses in the motor gearing, nor the friction except that caused by rolling which, however, cannot be separated from the power actually required to displace the metal. In general, it may be stated that if the machines are designed to withstand a current of about 2½ times the normal that could be carried continuously, the maximum capacity and the heating will be in about the right relation although this may vary according to local conditions. There is, however, a considerable variation in the power requirements for different ingots and the average figures may easily be exceeded by 30 per cent to 40 per cent, and considering the irregular rate of acceleration which may take place, a margin of at least 50 per cent should be allowed in the maximum capacity over the estimated average.

Reversing Mill of Illinois Steel Co.

As the only example of the reversing mill operating in this country a short description of the plant of the Illinois Steel Company may be of interest. It is of interest to note that this plant was designed in the middle of 1906 and put in operation in May, 1907, it being the third reversing mill in the world to be electrically driven.

The plant consists of a two-high universal plate mill, the general layout of which can be seen from Fig. 8 and a view of the completed mill is given in Fig. 9. This illustration, however, does not show the house around the motors. This mill is arranged to roll slabs 30 by 7 in. (76.2 by 17.7 cm.) down to plates ¼ in. (6.35 mm.) thick and is driven by two direct-current shunt type motors having a total rating of 8,000 h.p. maximum at 100 rev. per min., these machines being of the interpole compensated

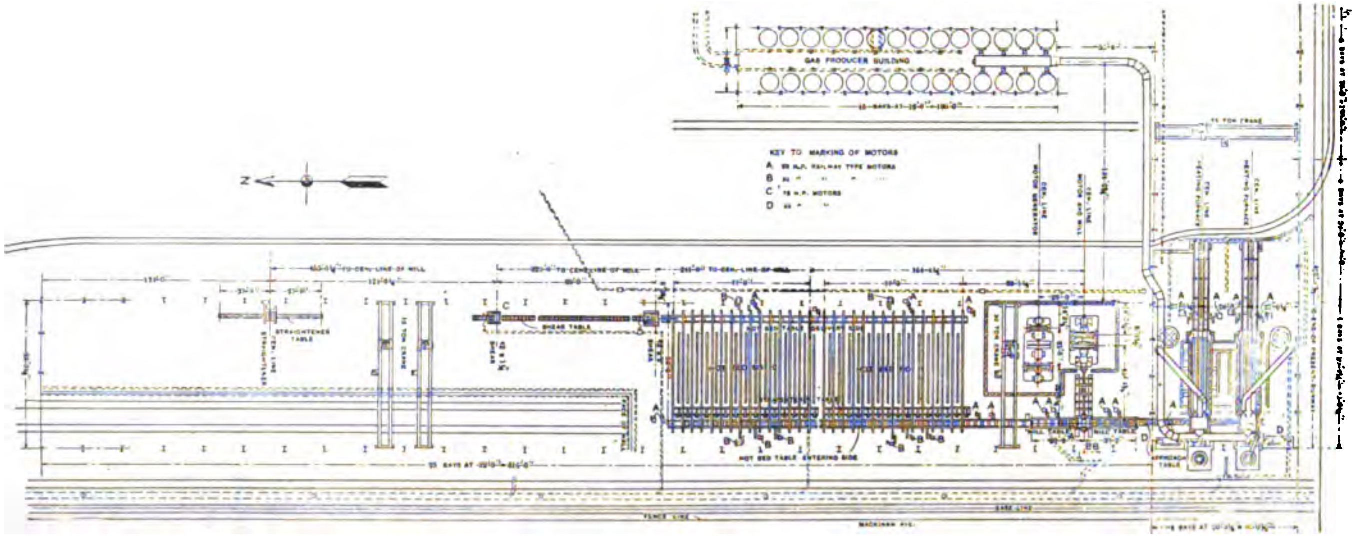


FIG. 8.—General layout of universal plate mill at the Illinois Steel Company's plant

type with a laminated field. The speed of the motors can be increased to 150 rev. per min. by weakening the field, but the controller is so arranged that they always start on full field. The motor was divided into two units in order to reduce the inertia to a minimum. In Fig. 10 the general arrangement of the motors is shown, the principal overall dimensions being also given. The weight of the stationary parts of the motors is approximately 233,000 lb. (105,687 kg.) and that of the rotating parts of the two motors 123,000 lb. (55,791 kg.) making the total weight of the machines about 356,000 lb. (161,478 kg.). The bearings of the motor are lubricated from a central oil tank and the overflow is filtered and returned to it to be used again.

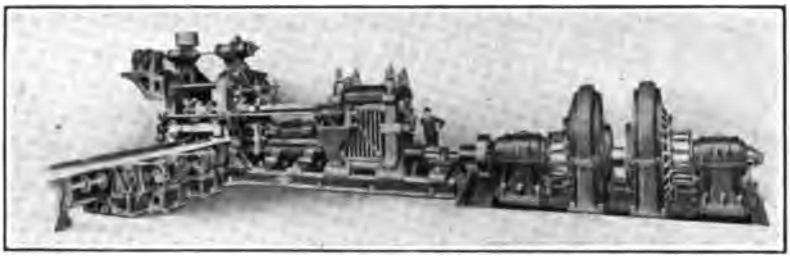


Fig. 9.—Universal plate mill at the Illinois Steel Company's plant, showing the motor drive

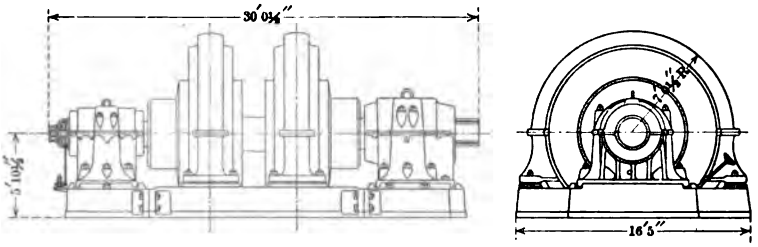


Fig. 10.—General layout of roll motors for driving universal plate mills

Water cooling is also provided. The outer face of the bearing next to the mill is babbitted, the coupling hub forming a thrust collar which bears against this surface of the motor and receives an end thrust from the mill.

The roll motors are operated from a motor-generator set consisting of 1,300-h.p. induction motor, 6,600 volts, 25 cycles, coupled to a double-commutator shunt type, generator and two flywheels each weighing 100,000 lb. (45,359 kg.). The synchronous speed of the set is 375 rev. per min., the peripheral speed of the flywheels being 15,500 ft. (4,724 m.) per minute.

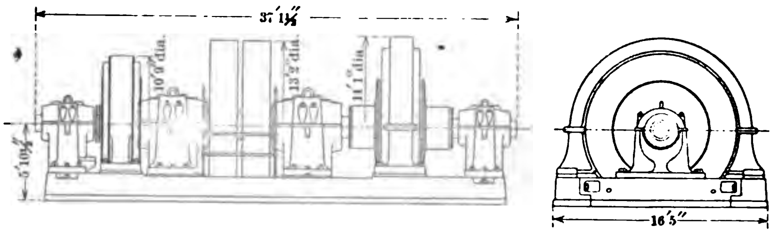


Fig. 11.—General layout of flywheel motor-generator set supplying power to roll motors

The generator armature has an inter-connected winding and each commutator supplies one of the roll motors. The maximum capacity of the machine is approximately 6,500 kw. corresponding to 8,000 h.p. at the motor. The generator has a completely laminated field and is of the interpole compensated type. The set has four bearings which are lubricated from a central oil tank, water cooling being arranged for the bearings supporting the flywheels. A general arrangement of the equipment is shown in Fig. 11 and a view of the completed machine is given in Fig. 12.

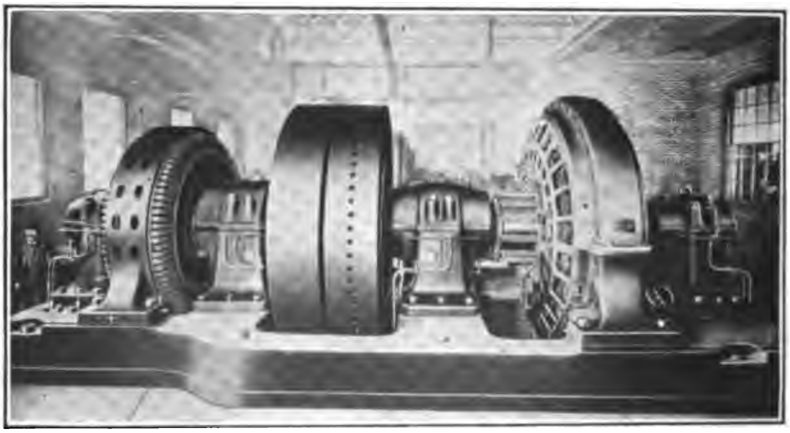


Fig. 12.—Motor generator set installed in the plant of the Illinois Steel Company

In order to start the set, a pneumatic barring gear is provided which assists the motor to overcome the initial friction. The total weight of the rotating parts is approximately 300,000 lb. (136,077 kg.) and that of the stationary parts 235,000 lb. (106,594 kg.) making a total of 535,000 lb. (242,671 kg.).

The speed of the set is regulated by an automatic slip regulator which consists of unit switches operated by two relays, one for dropping out the switches and the other for causing them to close, the difference between the settings being the limit within which the regulator operates.

The plant has been in continuous service for a number of years and the successful operation has completely borne out the experience gained in Europe with this class of equipment.

It was anticipated that when this paper was prepared it would be possible to give some characteristic curves from this mill but the tests have not been completed in time for publication.

In conclusion, the results that have been obtained with the reversing mills in operation have shown that the operation is equal to the best that is possible with steam-driven plants and in many cases very much better results have been obtained than with the steam plants that were displaced. The economy of this type of mill has been conclusively demonstrated and the only objection that has been raised is the high first cost. A little investigation, however, of the economy of the mill shows that the additional initial expenditure is very quickly saved by the lower power consumption. The rapid extension of this type of mill is sufficient demonstration of the fact that in new plants, where economy in operation is the controlling feature, the electrically driven reversing mill will eventually displace the steam-driven plants.

DISCUSSION ON "ELECTRICALLY DRIVEN REVERSING ROLLING MILLS." CHICAGO, JUNE 28, 1911.

Karl A. Pauly: I wish to call attention to Fig. 2, which shows the relative economy of the two types of mill. On examination of these curves it will be seen that the power consumed by reversing and non-reversing mills is practically the same from one-half load to 50 per cent overload, the difference being only five per cent and in favor of the reversing mill at loads of 90 per cent of full load and below, and in favor of the non-reversing mill at loads above 90 per cent of full load.

While the percentage difference in power consumed by the two types of mill is considerable at light loads, the actual difference in power consumed is comparatively small and should have little effect on the total power consumed by a well designed mill.

Further, the real measure of the efficiency of a mill is the cost per to nto roll the steel, including in this cost the fixed charges on the total investment properly chargeable against the mill and the total operating costs, including the costs of labor, maintenance, repairs, supplies and power.

A reduction in the power consumed affects one item only of the total cost of rolling, while the improvement in the quality of the product or an increase in the output affects all the factors, and those questions are usually the determining factors in the choice of the type of mill.

The speed with which steel can be rolled depends, among other things, on the shape and size of the section, it being possible and often necessary to roll a small simple section at a higher speed than a large irregular section. From this it follows that where a large variety of sections are to be rolled in a single mill, as is frequently the case in small plants, it is often more economical to adopt the reversing mill with its wide range of speed than the three-high mill, the range of speed of which is limited.

However, in America the tendency in modern plants is to specialize the products of the mills, rolling a limited variety of sections, either directly from the ingot or from prepared billets in large continuous mills made up of several stands of rolls. In a mill of this type but a few passes and in many cases but one pass is rolled in a single stand. A mill of this type can obviously be driven either by a number of constant speed non-reversing motors, one per roll stand, or a single motor geared to the several stands. All but one of the mills at Gary and many of the modern steam driven mills are of this type.

There is a class of mills known as universal mills which, because of the difficulty of building a three-high mill of this type and the small difference in cost between the reversing and non-reversing steam engine, has been practically universally driven by reversing engines. The very high cost of the electrically driven reversing rolling mills led to the development of a non-reversing universal mill, an example of this type being the

60-in. universal plate mill at the Gary works of the Illinois Steel Company. This mill is driven by a 6500-h.p., two-speed, changeable-pole, induction motor.

Also with a view of improving the economy of existing reversing mills and avoiding the high first cost of the electrically driven reversing mills, it has been proposed to operate low pressure turbines in conjunction with these mills, a regenerator being installed between the engine and the turbine.

While a number of electrically driven reversing mills will doubtless be installed in America, the indications are that the number will be much more limited than has been the case in Europe.

The slip regulator described may be made extremely sensitive by the use of ball bearings; in fact, we have built such a regulator which, when operating at full load, held the demand for power within two per cent either side of the mean.

Dr. J. Puppe has made a large number of tests to determine the power required for rolling steel of various sections and carbon contents. These tests and others indicate that when steels containing a considerable variation of carbon contents are rolled at the same temperature, the power consumption for a given elongation varies only slightly with the variation in carbon content.

It is pointed out in the paper that the curves given in Fig. 7 apply only to a limited number of sections. We have made extensive tests with a view of determining the power required to roll sections which differ widely from those given, such as sheets and plates both hot and cold rolled, and find that the power required for a given elongation may be much greater than that shown. Further, the friction varies widely with different types of mills, the friction load of some mills such as cold mills being a large percentage of the total power consumed.

In contrast with the cold mills we have the puddle mills. The power required during the early passes for a given reduction is much less when rolling puddle bar than when making a similar reduction in solid steel.

F. G. Gasche: The object in preparation of this paper is stated on the first page to be: " To briefly review the more important points in the design and operation." As the development of the subject matter introduces many observations to which we might not all agree, a specific analysis of such observations may be advisable in order to uncover, if possible, the economic tendencies in rolling mill practice and design.

Two questions can be propounded at the outset, and will serve to illustrate the attitude of the iron and steel interests today on the roll drive problem if we may judge by the treatment accorded to these matters in the recent past.

1. Is the reversing rolling mill advisable or necessary?
2. Is the Ilgner system the best method of driving the reversing rolling mill?

The reversing mill has been attractive to mill operators for reasons that have been stated as applying to European practice, *viz.*, facility in accommodating rapid changes in class of product and particularly for small orders in each class. A prominent advantage of the reversing mill consisted in the ready application of vertical rolls, operating simultaneously with the main rolls and effective in squaring the edges of slabs, plates and bars, where such a contour is desirable. The production of sharp corners on rolled sections is difficult with grooved rolls characteristic of the three-high or continuous train construction of rolls. Another advantage, which with modern construction is less apparent, is the absence of lifting or tilting tables peculiar to the three-high mill construction. Withal, the reversing mill offered a cheap and flexible mill construction, easily adaptable to a wide range of product and particularly attractive to the small plant and erratic demands for product.

The transformation from reversing mills to three-high construction commenced before the application of large electric motors to roll trains was a possibility. Commencing with the smallest roll trains and with better constructions available there has been a gradual appropriation of a certain part of the rolling mill business by the three-high trains such that there is scarcely a class of product which is not rolled by the three-high or continuous train with advantage over the reversing train. The part of the rolling mill work that has been thus diverted to three-high mills consists of the assured heavy orders of a given class of product sufficient to meet the capacity of the mill. The simple reason for this evolution of mill types is the commercial advantage after a certain state of business is realized at a given mill. I take exception to the observations of paragraph 2 above Fig. 1 of the paper, as it is contrary to the experience with the two types of mills, irrespective of the method of driving the same, with the foregoing qualifications concerning the class of mill orders.

The author of the paper has apparently overlooked the fact that reversing mills necessarily involve the inclined " spindles " or connections from driving mechanism to the rolls, the angular position of which imposes very heavy end thrusts on roll necks and other rotating parts in the system. Under the conditions of service the work lost in friction is certain to be a larger percentage with the reversing mill than with a properly aligned three-high train. The assertion in the second paragraph concerning the loss of continuously operating train as compared with the motor generator set remains to be proved, as the continuous train motor can be stopped when the service of the mill is interrupted, but the nature of the alternating current motor-direct current generator operation precludes anything like such intermittent service.

A recently completed three-high mill at the Gary Works, which the members of the Institute will examine, operates on a class of product and service which heretofore was considered the domain of the reversing mill. A continuously rotating induction motor with a suitably large flywheel is capable of ready control to two rotative speeds, which range is sufficient to meet the requirements of great variations in the size of slab and class of product. Vertical rolls have been retained, while tilting tables serve for manipulations of the slabs with an expenditure of energy that is insignificant in comparison with the irrecoverable energy losses due to impact of gears, spindles and other connections inseparable from the reversing mill construction. It may be added that the Ilgner system of drive was carefully considered for this particular mill and was abandoned for the following reasons:

1. The combined efficiencies of transmission and transformation of energy from shaft of prime mover to rolls was less than the three-high construction would offer.
2. The cost of the Ilgner system was prohibitive in comparison with the type that was adopted.

With the movement toward concentration of rolling mill work in large mills especially adapted to segregated classes of product and the accompanying continuous service, the economic tendencies answer the first question and indicate that in the ultimate development in this country the reversing mill is neither necessary nor desirable.

The second question as to the suitability of the Ilgner drive for reversing mills brings up the subject of overall efficiencies from prime mover to roll train, and cannot be disposed of by the comparisons referred to above Fig. 6. The Ilgner system involves from prime mover shaft to rolls three transmissions of energy and four transformations of energy, the continued product of the efficiencies for which must be compared with the efficiency of transmission of a direct-connected prime mover. Without exhibiting the actual efficiencies applying to the operation of a certain Ilgner system, it can be stated that a mechanical advantage in the ratio of almost two to one exists in favor of the direct connected prime mover.

The construction referred to below Fig. 6 in the paper is today obsolete in view of the demonstrated possibilities of non-condensing compound steam engine combined with the most recent types of low pressure turbo-generator sets.

R. Tschentscher: Mr. Sykes mentions that the pioneer work in reversing rolling mill motor drive occurred abroad. I wish to relate the following in this connection as it is quite possible that some credit should remain in this country:

Approximately December, 1905, at the South Works of the Illinois Steel Company, I installed a reversing drive motor-generator set consisting of 25-h.p., 250-volt, compound motor, coupled to a 75-h.p., 250-volt, compound motor, which drive was coupled to three 8-in. by approximately 50-in. diameter steel slabs as flywheels. The 75-h.p. motor on this set, acting as generator, was connected to a 75-h.p. motor of same type geared to a small train of two-high rolls. Crop ends of rails were cut in two lengthwise and the heads were rolled into flats in this train of rolls. The operation of this small experimental drive convinced the Illinois Steel Company engineers of the practicability of such a drive on a larger scale. Specifications were accordingly arranged for the purchase of entire electrical equipment for a two-high reversing 30-in. universal plate mill, placed in operation June, 1907.

It is somewhat difficult to discuss reversing rolling mill drives without introducing the question of the relative merits of two-high and three-high mills. A few points in this connection are offered.

Reversing two-high mills have the following commercial advantages over three-high mills.

1. Instant stopping of reversing mill in case of trouble—broken spindle, roll, collar, accident, etc.

2. Less maintenance cost of two-high reversing mill equipment. This is due to less operating parts, smaller weight of operating parts, less actual time of operation of parts and more "trouble-anticipating jobs" performed, due to the convenient and ready means of shutting down mills for short periods.

3. In smaller plants, it is very desirable that a miscellaneous assortment of finished product should be obtained from a mill. This can be better accomplished in a two-high than a three-high mill. In a two-high mill, rails, shapes, plates and merchant steel may be obtained while in the three-high mill one is practically limited to a single kind of finished product. In plants comprising a considerable number of different mills, this factor is not so important in times of full operation of the plant. However, in times of partial operation, due to business conditions, the large plant assumes the characteristics of the small plant. For the past few years, this point has assumed considerable importance and we are not certain that this condition of affairs will not exist for a considerable period in the future.

4. As a general statement, the percentage of salable product is higher on a two-high mill than on a three-high mill, due in a large measure to the speed control of the two-high mill permitting a slower forging operation during the early passes and high speed rolling operation during the last passes.

5. The relative amount of finished product obtained from a two-high and a three-high mill is not easily determined. Practically all depends upon local considerations, the size and shape of the initial ingot and the size and shape of the finished product being the governing factors. In a mill rolling finished 8-in. by 8-in. billets from ingots of large size, it is probable that the three-high mill has more capacity. In a plate mill rolling from slabs to finished plates, it is probable that the two-high mill has the greater capacity.

6. Less roll friction load for two-high mills. The power re-

quired for driving motor-generator set will vary from approximately 50 to 200 kw. compared with 300 to 800 kw. for three-high mills.

7. Starting load on three-high mill is very much in excess of that of motor-generator set on two-high mill in spite of any commercial barring motor arrangement which may be installed. This means, of course, a severe tax on power stations and, to this extent, larger power stations are required for three-high mills. In small plants or in those purchasing power, this becomes quite a serious item. In larger plants, this point is not so serious.

8. The question of relative efficiency of reversing and continuous rotation drive is not easy of disposition. If the full load operating conditions of the local electrical drive are considered, then the economy of the three-high is no doubt better than that possible with any two-high drive under the same conditions. However, the use of such figures in a commercial analysis on the basis of steel mill operating conditions such as they *are* (not as we would like to have them) will prove very misleading. An attempt must be made to arrive at the yearly economy. This is affected by a large number of, at the present time, uncontrollable factors in the local mill. The intermittent operation of steel mills due to orders—or lack of orders—local mill operating conditions such as operation of reheating furnaces, congested hot beds, mill breakdowns, etc., plant operating conditions such as irregular steel supply due to a large number of causes out of the control of the local mill, are of much more importance in influencing the question of yearly economy than the relative figure of full load economy of the electrical equipment. Furthermore, the power station demands will be greater and the peak loads higher with a three-high mill than with a two-high mill and the yearly economy of the power generating equipment, under such conditions, is an important factor.

9. The higher first cost of two-high reversing mill electrical equipment is compensated for to a considerable extent in the three-high mill, by materially higher first cost of mill proper and by higher investment due to the larger power generating equipment being required. No broad general statement can be made to cover the point of the relative first cost of reversing mill equipment and three-high mill equipment. Each condition must be analyzed but in such an analysis, one must not cease calculations after covering the electrical equipment *within* the roll motor room. As mentioned, the cost of the mill equipment and the cost of the transmission and generating system must be seriously taken into consideration.

Theodore Hoock: Mr. Sykes presented a complete and up to date table of all reversing rolling mill installations.

The power consumption of this kind of service is the most severe and variable one on the machines. The maximum output runs up to 15,000 h.p. and the momentary overload reaches 5 to 6 times the normal rating. In addition the motors are to be reversed continuously, which requires brush setting at the neutral from full speed in one direction to full speed in the other direction within three to five seconds.

Referring to the installations No. 1, 2 and 4 in the table, which were built in 1905 to 1907, the following points were leading in choosing the type of generator and motor.

The sparkless commutation was only obtainable by auxiliary poles. The sudden peak loads made the distributed compensating winding desirable for several reasons. The quick variations of the armature field cause a corresponding increase of the voltage between segments underneath the pole tips which leads to flashing in case no compensating winding is provided in the pole face. That is especially the case when the main field is weakened. The segment voltage remains almost constant with the compensating winding at any load and a smaller number of commutator bars is feasible. The maximum voltage between segments can also be kept low with the auxiliary pole type, but it requires a considerably larger number of bars, that is a larger and longer commutator. Since the compensating winding prevents field distortion it is feasible to build this type with a smaller air gap, which has the advantage of decreasing the air gap ampere turns and the time constant of the main field winding of the generator. The quick field reversing, the small remanence in the yoke iron and the lower reactance of the field coils decided for the laminated yoke and the compensating winding. The laminated yoke has also the advantage that the commutating field path has practically the same permeance as the armature and the commutating field is built up as quickly as the armature current has to be commutated to prevent sparking and flashing.

The inertia of the motor is to be small which leads to a small diameter and long core. A low speed auxiliary pole machine with bodily poles and solid yoke and 20 in. core length is difficult to keep cool. The large rolling mill motors No. 2 and No. 4 could have double this length because the yoke iron was laminated in line with induction motor practice.

Wilfred Sykes: With reference to the remarks of Mr. F. G. Gasche regarding the possibility of rolling all classes of materials on three-high mills, I believe this is not doubted by any one familiar with rolling mill practice—the question as to whether it is advisable, however, is open to discussion. As pointed out by Mr. Tschentscher, the reversing mill is of particular value in a small plant, but this type of mill can also be used to very great advantage in the larger plants for rolling small quantities of largely varying material, which would be difficult with a three-high mill. Mr. Tschentscher's statement that a large plant in bad times approximates very closely the operating characteristics of a small plant, seems to me to state the case very well.

Mr. Gasche takes exception to the statement that the reversing mill is more economical than the three-high mill when working on partial output, as being contrary to experience with this class of mill. I presume that he refers to steam driven mills, as this is certainly not the case with electrically driven mills, as has been repeatedly demonstrated in Europe.

The statement that the continuously running motor may be stopped during intervals applies equally well to motor-generator sets, as it is common practice to cut off the current from the driving motor of the motor-generator set and let it coast when the interval is likely to exceed 10 or 15 minutes.

The reference to the three-high 60-inch plate mill at Gary raises the question which cannot be disposed of without some discussion. This mill is driven by a two-speed motor of 53½ and 107 rev. per min., the roughing passes being made at the slow speed and the finishing passes at the high speed. This necessitates accelerating the motor from 53 to 107 rev. per min. during the rolling of each plate and retarding the motor when the plate is finished in order to have the correct speed for the next slab.

On account of the low speed of the motor during the first passes, it is necessary to have considerable flywheel effect in order to obtain a reasonable equalization of the load. At the high speed when the stored energy is four times as great, the flywheel effect is not so important as the power requirements are usually less for the finishing than for the roughing passes due to the fact that the amount of work that it is possible to do on the plate per pass is limited by what the material will stand without injury, consequently the maximum loads are not so great as when roughing.

In order to facilitate the changing of the motor speed the flywheel effect shoud be as little as possible, otherwise considerable time and energy will be lost. It will be seen that the two operating conditions, with such an arrangement, are antagonistic.

In the case of a reversing mill, the inertia of the motor is kept as small as possible, and therefore it is easy to obtain the higher speeds for finishing. The flywheel of the motor-generator set takes care of the fluctuations in power and consequently it is possible with the reversing motor to obtain a large range of speeds and operating conditions, at the same time to effectually equalize the load on the power plant.

With the arrangement at Gary two speeds only are obtainable, whereas with the reversing mill a gradual increase is possible and thereby a great average speed is obtained which enables the output to be increased. This is of particular value when rolling long plates and reduces the power consumption as with quicker rolling the final temperature is higher.

Regarding the statement that the inclined spindles of the two-high mill cause the considerable losses, this is contrary to tests made by the writer which indicate that there is very little difference in the friction load of a properly designed mill, no matter what the position of the rolls may be.

Mr. Gasche's statement that the Ilgner system is less economical than the direct-connected motor, on account of the various transformations, would appear on the face of it to be correct, but as pointed out in the paper, this is not the only feature to be considered and the curves shown are the results of tests made on various mills and indicate that as far as the power required from the line for a certain rolling work is concerned, there is at full load very little difference between the three-high and the reversing mill.

When the question of the input to prime movers is considered, the only basis of comparison should be the number of heat units required for the various systems. In order to clear up this point, I have prepared a number of curves, see Fig. 1, which show the results obtainable with various arrangements. In order to compare the different methods of driving, I have reduced all results to the number of heat units required in the fuel to roll the steel. These figures are on the basis of rolling ingots to blooms or billets or similar work when only direct pressure comes in question and the temperature range is from about 2200 deg. fahr. to 1800 deg. fahr. The values shown are the heat units required in the coal or gas and all the various losses that occur have been considered. Curve No. 4 shows the results obtained from a test on a double tandem reversing engine of the latest construction built in 1909, the exhaust steam being used by a suitable turbine coupled to generator. The steam consumption figures are the result of a test extending over 16 hr. during which 645 tons of ingots were rolled to billets of various sizes. In separating the output of the turbine and engine, I have divided the total heat units in pro-

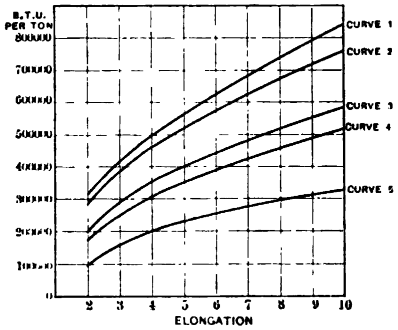


Fig. 1

Heat units required per ton for rolling blooms or billets in reversing mill at full capacity
Curve No. 1.—Steam drive saturated steam condensing 130 lb. 26 in. vacuum.
Curve No. 2.—Steam drive superheated steam 80 deg. fahr. 130 lb. 26-in. vacuum.
Curve No. 3.—Electric drive turbine driven generators steam 150 lb. 100 deg. fahr. superheat 28 in. vacuum.
Curve No. 4.—Steam drive combined with exhaust steam turbine 130 lb. 80 deg. fahr. superheat 28 in. vacuum.
Curve No. 5.—Electric drive gas engine driven generators.

portion to the actual work performed by each. During these tests, the average steam pressure was 130 lb., the superheat 80 deg. fahr. and the vacuum about 28 in. so that the conditions were such as to give results as favorable as could be expected with such an arrangement. The loss in the piping has been taken at 5 per cent, which corresponds to the average condition and the boiler efficiency has been taken at 70 per cent, which was the figure obtained during a four weeks test at the same plant, the boilers being of the watertube type with chain grates. Curve No. 2 shows the steam consumption of the engine working without the turbine and exhausting direct into the condenser. These figures check very closely with those of Ortmann (*Stahl and Eisen*, 1908, page 577)—made on similar plants and are based on the same steam conditions as when running with the turbine. To show the effect of the superheat, curve No. 1 has been drawn, which shows the consumption when running condensing with saturated steam.

In order to compare an electrically driven mill with turbine driven generators, curve No. 3 has been worked out from results obtained with electric drive and on the basis of a steam consumption of 17½ lb. per kw-hr., at 70 per cent load factor, 150 lb. steam, 28 in. vacuum, 100 deg. superheat.

The lowest heat consumption is that with gas driven generators and electric drive. Tests in this country and abroad show that an average thermal efficiency of 20 per cent is obtainable with gas engines with a load factor of about 70 per cent and taking the results of tests on electrically driven mills, the combined figures have been obtained, which check up closely with European results. A load factor of 70 per cent on the machines has been assumed as it is quite possible to obtain this value under normal operating conditions and in a well run station it would be exceeded, but this should not be confused with the load factor of the station.

From these curves it will be seen that the gas-driven generator and electrically driven mill is by far the most economical arrangement and as most modern steel plants are using the blast furnace gases directly in gas engines for the production of power, it is plain that the electrically driven mill presents great advantages from the standpoint of economy. The use of electricity allows of the disposition of the plant in any way convenient, whereas with steam-driven mills, they must be located in relation to the boiler house and this necessarily imposes restrictions which cause the plant to become congested. The figures given for the steam driven plant with exhaust turbine are the best that can be obtained and do not take into consideration the effect of interruption in operation of the mill when live steam must be used to keep the turbine running. In the case of a reversing mill, the actual time the engine is running is comparatively short and when work is irregular, it is often necessary to use live steam. Experience in Europe tends to show that the net economy of the combined engine and turbine over a year's run, is practically the same as the electrically driven mill furnished with power by high-pressure turbine driven generators, although in the opinion of some operators, it is a good deal lower. The disadvantage from an operating standpoint of such an arrangement which involves so many restrictions, does not in my opinion justify its adoption for new plants. As will be seen from the curves the saving that can be made with this arrangement under the most favorable conditions assuming that live steam is never necessary, is in any case not very great.

Mr. Gasche's statement that the use of a throttle valve between the receiver and the low pressure cylinder is obsolete, does not line up very well with modern practice. For a statement as to the modern practice for reversing rolling mill engines, see *Stahl and Eisen*, January 19, 1911, page 97.

That the first cost of the reversing mill electrical equipment is greater than that of a three-high mill, is obvious, but when the total cost of the installation including the mill itself and all auxiliary equipment is considered, the extra cost is surprisingly small and this is of course the only basis on which any comparison can be made. The effect that the type of drive has on the generating station is of the utmost importance and as pointed out by Mr. Tschentscher, it is not only the equipment in the motor room that must be considered.

Regarding Mr. Tschentscher's remarks, it is very interesting to note the experiments made at the South Works of the Illinois Steel Co. in 1905 and there is no doubt that a great deal of credit is due to the engineers of the company for the installation of the reversing plate mill at these works. As mentioned in the paper, this mill was designed and was being constructed before the first European installation was started. With reference to the curves given in the paper showing power requirements, it should be noted that these represent average figures. Tests show very widely varying results due to a number of causes, but the figures given may be taken as representative of the results obtained when rolling simple sections of moderate size. When rolling smaller sections, the power will be greater as the metal is liable to become colder. The power required may also vary with the quality of steel; this however, is not due to the chemical composition, but rather to the fact that high carbon steel must be rolled at a lower temperature than low carbon steels. Tests indicate that at temperatures above 900 deg. cent. the chemical composition of the steel has practically no influence upon this strength.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES

BY GEORGE O. SQUIER

I. INTRODUCTION

Electrical transmission of intelligence, so vital to the progress of civilization, has taken a development at present into telephony and telegraphy over metallic wires; and telegraphy, and, to a limited extent, telephony, through the medium of the ether by means of electric waves.

During the past twelve years the achievements of wireless telegraphy have been truly marvelous. From an engineering viewpoint, the wonder of it all is, that, with the transmitting energy being radiated out over the surface of the earth in all directions, enough of this energy is delivered at a single point on the circumference of a circle, of which the transmitting antenna is approximately the center, to operate successfully suitable receiving devices by which the electromagnetic waves are translated into intelligence.

The " plant efficiency " for electrical energy in the best types of wireless stations yet produced is so low that there can be no comparison between it and the least efficient transmission of energy by conducting wires.

The limits of audibility, being physiological functions, are well known to vary considerably, but they may be taken to be in the neighborhood of 16 complete cycles per second as the lower limit and 15,000 to 20,000 cycles per second as the upper limit. If, therefore, there are impressed upon a wire circuit for transmitting intelligence harmonic electromotive forces of frequencies between 0 and 16 cycles per second, or, again, above 15,000 to 20,000 cycles per second, it would seem certain that whatever effects such electric wave frequencies produced upon metallic lines, the present apparatus employed in operating them could not translate these effects into audible signals.

There are, therefore, two possible solutions to the problem of multiplex telephony and telegraphy upon this principle by electric waves, based upon the unalterable characteristics of the human ear, *viz.*, by employing (1) electric waves of infra-sound frequencies, and (2) those of ultra-sound frequencies. One great difficulty in designing generators of infra-sound frequencies is in securing a pure sine wave, as otherwise any harmonic of the fundamental would appear within the range of audition. Furthermore, the range of frequencies is restricted, and the physical dimensions of the tuning elements for such low frequencies would have a tendency to become unwieldy.

The electromagnetic spectrum at present extends from about four to eight periods per second, such as are employed upon ocean cables, to the shortest waves of ultra-violet light. In this whole range of frequencies there are two distinct intervals which have not as yet been used, *viz.*, frequencies from about 3×10^{12} of the extreme infra-red to 5×10^{10}, which is the frequency of the shortest electric waves yet produced by electrical apparatus, and from about 80,000 to 100,000 cycles per second to about 15,000 to 20,000 cycles per second. The upper limit of this latter interval represents about the lowest frequencies yet employed for long distance wireless telegraphy.

Within the past few years generators have been developed in the United States giving an output of two kilowatts and above at a frequency of 100,000 cycles per second, and also capable of being operated satisfactorily at as low a frequency as 20,000 cycles per second. Furthermore, these machines give a practically pure sine wave.

The necessary conditions for telephony by electric waves guided by wires are an uninterrupted source of sustained oscillations, and some form of receiving device which is quantitative in its action. In the experiments described in multiplex telephony and telegraphy it has been necessary and sufficient to combine the present engineering practice of wire telephony and telegraphy with the engineering practice of wireless telephony and telegraphy.

The frequencies involved in telephony over wires do not exceed 1800 to 2000, and for such frequencies the telephonic currents are fairly well distributed throughout the cross section of the conductor. As the frequency is increased the so-called " skin effect " becomes noticeable, and the energy is more and more transmitted in the ether surrounding the conductor.

It has been found possible to superimpose, upon the ordinary telephonic wire circuits now commercially used, electric waves of ultra-sound frequencies without producing any harmful effects upon the operation of the existing telephonic service. Fortunately, therefore, the experiments described below are constructive and additive, rather than destructive and supplantive.

Electric waves of ultra-sound frequencies are guided by means of wires of an existing commercial installation and are made the vehicle for the transmission of additional telephonic and telegraphic messages.

APPARATUS AND EQUIPMENT

Under a special appropriation granted to the Signal Corps by Congress in the Army Appropriation Act of 1909, a small research laboratory has been established at the Bureau of Standards, in the suburbs of the city of Washington. This laboratory is equipped with the latest forms of apparatus now employed in the wireless telephone and telegraph art, and also with the standard types of telephone and telegraph apparatus now used upon wire circuits. The small construction laboratory of the U. S. Signal Corps is located at 1710 Pennsylvania Avenue and is also equipped with the usual types and forms of apparatus used in transmitting intelligence by electrical means. Each of these laboratories is supplied with a wireless telephone and telegraph installation with suitable antennæ. In addition, these two laboratories are connected by a standard telephone cable line about seven miles in length, which was employed in the experiments described below.

THE 100,000-CYCLE GENERATOR*

The high-frequency alternator, which is shown complete with driving motor and switchboard in the accompanying illustrations, is a special form of the inductor type designed for a frequency of 100,000 cycles with an output of two kw., making it adapted for use in wireless telephony or telegraphy.

Driving Motor. The motor is a shunt-wound 10-h.p. machine with a normal speed of 1,250 rev. per min. It is connected by a chain drive to an intermediate shaft which runs at a speed of 2000 rev. per min. The intermediate shaft drives the flexible

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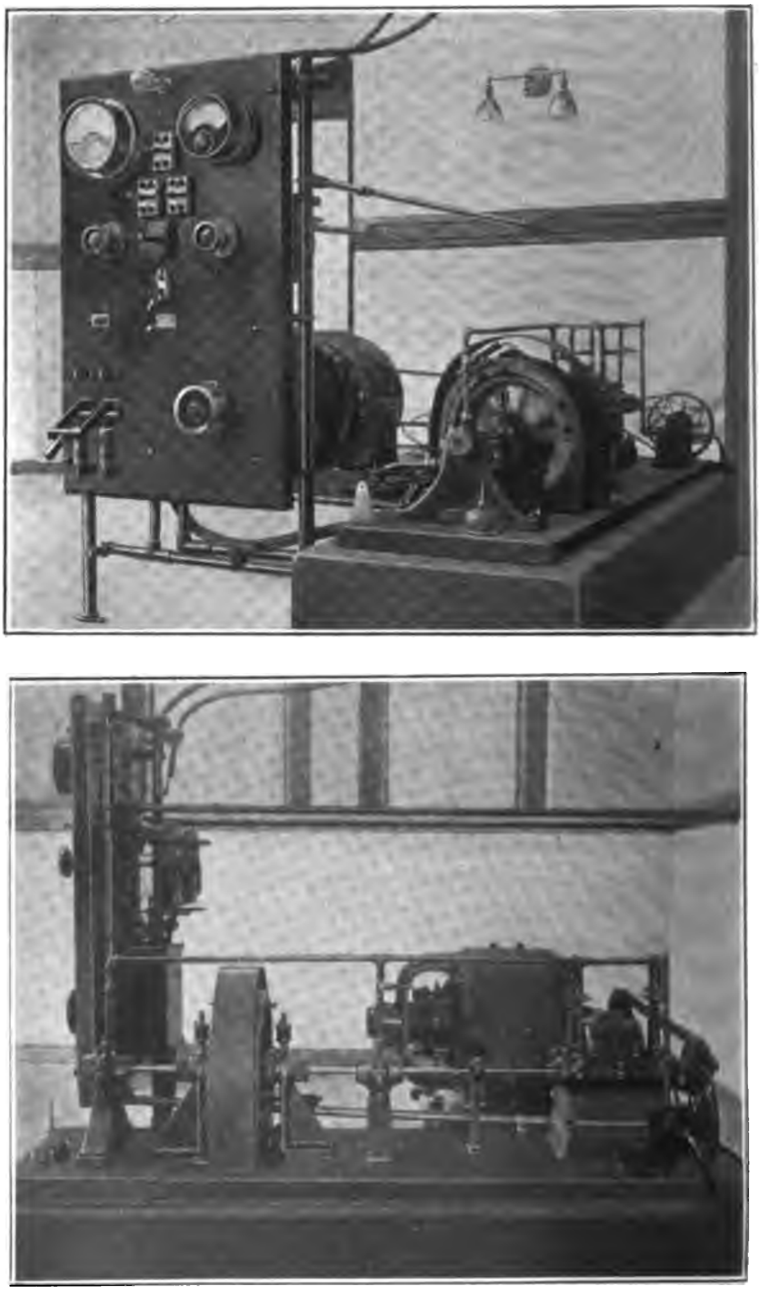
*Alexanderson, TRANS. A. I. E. E., Vol. XXVIII, p. 399, 1909.



Front and rear view of high-frequency alternator, driving motor and switchboard shaft of the alternator through a De Laval turbine gearing, having a ratio of ten to one. The flexible shaft and inductor thus revolve at a speed of 20,000 rev. per min.

Field Coils. The field coils, mounted on the stationary iron frame of the alternator, surround the periphery of the inductor. The magnetic flux produced by these coils passes through the laminated armature and armature coils, the air-gap, and the inductor. This flux is periodically decreased by the non-magnetic sections of phosphor-bronze embedded radially in the inductor at its periphery.

Armature Coils. The armatures or stators are ring-shaped and are made of laminated iron. Six hundred slots are cut on the radial face of each; a quadruple silk-covered copper wire, 0.016 in. (0.4 mm.) in diameter, is wound in a continuous wave up and down the successive slots. The peripheries of the armature frames are threaded to screw into the iron frame of the alternator. By means of a graduated scale on the alternator frame the armatures can be readily adjusted for any desired air-gap.

Inductor. The inductor or rotor has 300 teeth on each side of its periphery, spaced 0.125 in. (3.17 mm.) between centers. The spaces between the teeth are filled with U shaped phosphor bronze wires, securely anchored, so as to withstand the centrifugal force of 80 lb. (36.3 kg.) exerted by each. Since each tooth of the inductor gives a complete cycle, 100,000 cycles per second are developed at 20,000 revolutions per minute. The diameter of the disk being one foot (0.30 m.), the peripheral speed is 1,047 ft. (319 m.) per sec., or 700 miles (1127 km.) per hour, at which rate it would roll from the United States to Europe in four hours. By careful design and selection of material, a factor of safety of 6.7 is obtained in the disk, although the centrifugal force at its periphery is 68,000 times the weight of the metal there.

Bearings. The generator has two sets of bearings, as shown in the illustrations, the outer set being the main bearings which support the weight of the revolving parts. These bearings are self-aligning and are fitted with special sleeves, which are ground to coincide with longitudinal corrugations of the shaft, thus taking up the end thrust. A pump maintains a continuous stream of oil through these bearings, thus allowing the machine to be run continuously at full speed without troublesome heating.

The middle bearings normally do not touch the shaft, but take up excessive end thrust and prevent excessive radial vibration of the flexible shaft.

An auxiliary bearing or guide is placed midway between the gear box and the end bearing. Its function is to limit the vibration of that portion of the shaft.

Critical Periods. In starting the machine, severe vibration occurs at two distinct critical speeds, one at about 1,700 and the other at about 9,000 revolutions per minute. The middle bearings prevent this vibration from becoming dangerous.

Voltage. With the normal air-gap between the armatures and revolving disk of 0.015 in. (0.38 mm.), the potential developed is 150 volts with the armatures connected in series. It is possible, however, to decrease the air gap to 0.004 in. (0.10 mm.) for short runs, which gives a corresponding increase in voltage up to nearly 300 volts. It is considered inadvisable, however, to run with this small air gap for any considerable length of time.

The machine is intended to be used with a condenser, the capacity reactance of which balances the armature inductance reactance which is 5.4 ohms at 100,000 cycles. This would require a capacity of about 0.3 microfarad for resonance at this frequency, but in the experiments conducted at 100,000 cycles it was found necessary to decrease this amount on account of the fixed auxiliary inductance of the leads.

Constants of the Telephone Line

The telephone line used in these experiments extends from the Signal Corps laboratory at 1710 Pennsylvania Avenue to the Signal Corps research laboratory at the Bureau of Standards.

This line is made up of the regular standard commercial equipment and consists of paper-insulated, twisted pairs in lead covered cable, placed in conduit in the usual manner employed for city installation. For the sake of convenience one of the pair is designated as No. I wire and the other as No. 2 wire.

The air-line distance between the two laboratories is a little over three miles (4.8 km.), but the telephone line, by passing through three exchanges, covers about seven miles (11.27 km.). The course of the line, with the size and type of conductor, is as follows:

Laboratory to Main Exchange, underground cable, No. 22 B. & S.
Main Exchange to West Exchange, underground cable, No. 19 B. & S.
West Exchange to Cleveland Exchange, underground cable, No. 19 B. & S.

Cleveland Exchange to Bureau of Standards, underground cable, No. 19 B. & S.

All underground cable except from Bureau of Standards to Wisconsin Avenue and Pierce Mill Road, about 3,400 ft, which is aerial cable.

This line is equipped with protective heat coils of a standard type, one in each wire of the metallic circuit, at the Cleveland Exchange and the Main Exchange, but none at the West Exchange. The constants of each of these coils are as follows:

Direct current resistance of 65 deg. fahr.	3.8 ohms
Size of wire	No. 30 B. & S.
Length of wire	40 cm.
Number of turns in each coil, about	38
Measured inductance at 70,000 cycles	4,400 cm. or 4.4×10^{-6} henry

The above constants were measured from a sample of one of these coils selected at random.

Resistance of metallic circuit	=776 ohms
Capacity measured (one minute electrification) between No. 1 and No. 2 wires	=0.69 microfarad
Insulation resistance:	
Between No. 1 wire and earth	=0.9 megohms
" No. 2 wire and earth	=1.3 "
" No. 1 and No. 2 wires in parallel and earth	=0.8 "
" No. 1 and No. 2 wires	=2.1 "

The line included the usual house-wiring at each station, which was undisturbed in taking the measurements.

II. Duplex-Diplex Telephony over Wire Circuits

Such has been the development of telephone engineering that at present any proposal which requires for its success the supplanting of the present low frequency battery system would be most radical. It would surely be admitted that any plan which permits the present engineering telephone system to remain intact and superimpose thereon additional telephone circuits would possess cardinal advantages. Accordingly, the first preliminary experiments were directed to the inquiry as to whether or not it is possible to superimpose upon the minute telephonic currents now employed in telephony over wires, electric waves of ultra-sound frequencies without causing prohibitive interference with the battery telephone currents. Manifestly, this fundamental point can best be determined by experiments, at the generator itself, with the most sensitive part of the telephone equipment, *viz.*, the telephone receiver. Accordingly, experiments were first conducted with various forms and types of telephone receivers in connection with local circuits at the generator. Such is the sensibility of the telephone receiver that it was thought possible that, although currents of frequencies entirely above audition were applied to the receiver from a dynamo as a source, there might be some frequency or frequencies from the operation of the apparatus which would be within the range of audition. Such was found, in fact, to be the case at certain critical frequencies of the machine, but they were of no practical importance, as will be shown later.

With a collection of telephone receivers ranging from about 50 to over 8000 ohms and of a variety of designs, a series of tests was made under severe conditions to determine the above point. It was found, in general, that alternating currents of frequencies ranging from 30,000 to 100,000 cycles per second, when coupled conductively, inductively, or electrostatically to local circuits from the generator produced absolutely no perceptible physiological effects in the receivers, excepting only that at certain of the lower frequencies a distinct audible note could be faintly heard in one of the receivers of about 250 ohms resistance.

A search for the cause of this note showed that it is due to a slight variation of the amplitude of the high-frequency current of the generator, since no evidence of it could be detected on the battery telephone side of the circuit. It appears to be caused by a very slight vibration of the rotor as a whole in the magnetic field of the generator. It was almost entirely removed by the simple device of opening out the stators, which increases the clearance and materially cuts down the flux of the machine. In practice it is a distinct advantage, however, to have a trace of this note still left on the high-frequency side of the circuit, otherwise there is no ready means of determining at the receiving end of the cable line whether or not the high-frequency current is present on the line, whereas this note, which has to be searched for in tuning and which was entirely tuned out when speech was best, gave a very convenient method of testing for the presence of high-frequency current.

Having determined the general nature of this disturbance and its comparative unimportance, no further investigation of it was considered necessary at that time.

The next fundamental point to determine was whether or not at these frequencies a telephone can receive enough energy to make it operative for producing sound waves in air.

Since the self-induction of a standard telephone receiver is high, energy at these frequencies is effectively barred from it. In the wireless telegraph art, where the frequencies involved are from one hundred thousand to several million per second, this problem has been uniformly solved by the introduction of some form of detector for electromagnetic waves, whose function is to transform the energy of the high-frequency oscillations into other forms suitable to a type of instrument such as a telephone receiver.

The next step, therefore, consisted in introducing various forms of detectors, such as are now used in wireless telegraphy, between the telephone receiver itself and the energizing circuit. Since the frequencies being here considered are entirely above audition it was necessary, in order to produce a physiological effect, to introduce another element in this transformation, *viz.*, some method of modifying the continuous train of sustained oscillations from the generator into groups or trains, the period of which falls within the limits of audition. This was accomplished by employing the regular forms of automatic interrupters, such as are now used in wireless telegraphy, with the expected result that with these two additional and essential pieces of apparatus operatively connected between the telephone receiver and the generator, the energy of the generator was delivered to the ear in a form well suited for physiological effects. Since it is well known that the human ear is most sensitive at a period of about 500 cycles per second, or 1000 alternations, interrupters giving this frequency were employed.

The presence of the detectors in this chain of transformations is necessitated by the use of the telephone receiver as a translating device.

Although some of the detectors for electric waves are very sensitive to electrical energy they are here employed not because they are more sensitive to electrical energy than is the telephone receiver itself, which is not the case, but because the telephone receiver is not adapted, for the reasons stated above, to translate electrical energy of these frequencies into movements of its diaphragm.

The elements of the apparatus thus far include a generator of sustained high-frequency oscillations, an interrupter to modify the amplitude of these oscillations into groups of a period within the range of audition, some form of detector to rectify these oscillations, and a telephone receiver. Manifestly here are all of the elements that are necessary for telegraphy, using the telephone receiver to interpret the signals.

If in the above mentioned chain of apparatus the interrupter is replaced by some form of telephone transmitter, such as the microphone, this is all that is necessary for the transmission of speech.

Experiments were made over local circuits with apparatus arranged in this order over a range of frequencies from 20,000 to 100,000 per second, with the result that speech was transmitted very satisfactorily. Upon removing the detector from the above arrangement all perceptible effect in the telephone receiver ceased; in fact no arrangement of connections of a telephone receiver to such a high frequency circuit which did not include some form of detector was found to be operative for telephony, unless certain low resistance telephones were used in which case the speech was so much weaker as to be of an ***entirely different order of magnitude.***

The presence of a detector in this chain of operations is not absolutely necessary in the case of telegraphy, since if the interrupter automatically produces a definite number of wave-trains per second, each train consisting of at least several complete oscillations, an effect may be produced upon a telephone receiver directly without a detector. The physiological effect, however, is quite different, the clear fundamental note corresponding to the frequency of the interrupter being no longer audible, but, instead, a peculiar dull hissing sound. If, however, a telephone receiver was used, which, instead of having a permanent magnet as a core, had one of soft iron, no effect without the detector was produced with the energy used.

As stated above in the case of telephony, the energy required for telegraphy without a detector is of a different order of magnitude.

Having determined the necessary and sufficient conditions for the accomplishment of telegraphy and telephony by means of electric waves guided by wires upon local circuits, the next step was to apply these means and conditions to an actual commercial telephone cable line, the constants of which have been given above.

The machine was run at a frequency of 100,000 cycles per second with the circuit arrangements as shown in Fig. 1, where one wire of the telephone cable was connected to one terminal of the secondary of an air-core transformer, the other terminal being connected to earth.

At the receiving end of the line, which was the Signal Corps construction laboratory, at 1710 Pennsylvania Avenue, Washington, D. C., this wire was connected directly to earth through a " perikon " crystal detector, such as is well known in wireless telegraphy, and a high resistance telephone receiver of about 8,000 ohms was shunted around the crystal. In this preliminary experiment no attempt was made at tuning, either at the transmitting end or at the receiving end of the line.

In the primary circuit of the generator, arrangements were made by which either an interrupter and telegraph key or a telephone transmitter could be inserted by throwing a switch.

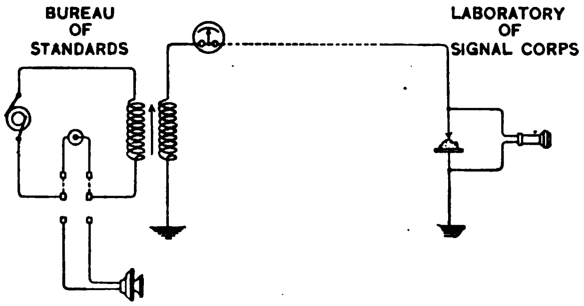


FIG. 1

In the line circuit a hot wire milliammeter was inserted in a convenient position so that the effect of the operation of either the telegraph key or of the human voice upon the transmitter could be observed by watching the fluctuations of the needle of the milliammeter.

A loose coupling was employed between the two circuits at the transmitting end, and the line circuit adjusted by varying the coupling until the current in the line was twenty to thirty milliamperes. With this arrangement (1) telegraphic signals were sent and easily received, and (2) speech was transmitted and received successfully over this single wire with ground return.

The ammeter showed marked fluctuations from the human voice and enabled the operator at the transmitting station to be certain that modified electric waves were being transmitted over the line.

The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles, since with one of the wires of the pair and a ground return, the effect of doubling the conductivity of the wire by joining both wires in parallel, although this arrangement increased the capacity of the wires, could not be detected with certainty by an operator listening to the signals and unaware of which arrangement was being used.

Inserting in the line wire a non-inductive carbon rod resistance of 750 ohms, which is practically the resistance of the line itself, could not be detected by any change in the intensity of the received signals.

The next experiment was to determine what effect, if any, such sustained electrical oscillations would have upon the minute telephonic currents employed in battery telephony.

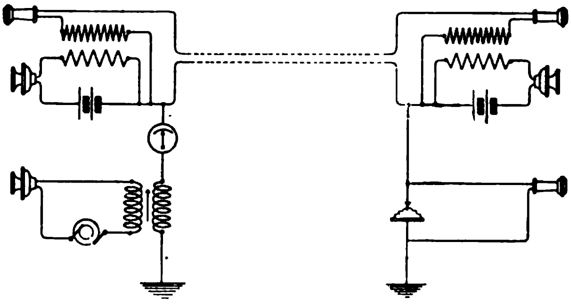


FIG. 2

DUPLEX TELEPHONY, USING ONE GROUNDED CIRCUIT

To determine the fact that electric waves of ultra-sound frequency produce no perceptible effect when superimposed on the same circuit over which telephonic conversation is being transmitted, the next step was to use such a train of sustained oscillations as the vehicle for transmitting additional speech over the same circuit. For this purpose the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, and in addition one of the wires of the pair was equipped as in Fig. 1, the circuit being shown diagrammatically in Fig. 2. This particular arrangement was employed in this experiment for the reason that it was desired to have the battery telephone operâte on its usual circuit with the introduction of ground connections at the ends of the line for the super-position of the high-frequency circuit. When such ground connections were introduced directly without tuning elements therein the metallic circuit experienced the usual disturbances found under city conditions, but the metallic circuit could be reduced to silence again by introducing in the ground connections the necessary tuning elements of magnitudes suited to wireless telegraphy.

Next, the twisted-pair telephone line was equipped with a

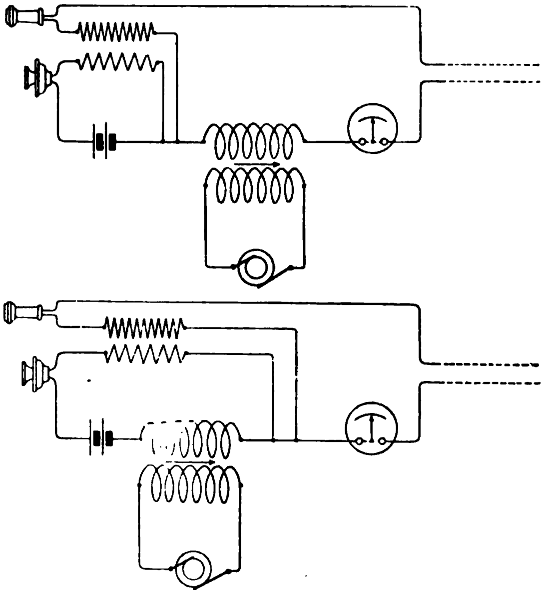


FIG. 3

complete standard local battery telephone set, as installed for commercial practice, with the exception that the local battery circuit of the transmitter telephone set was opened and a few turns of coarse wire inserted in series with the two dry cells which are normally used, as shown in Fig. 3. Inductively connected with this coil was the armature circuit of the generator. A hot wire milliammeter was placed in the line circuit to indicate the magnitude of the high frequency current which was flowing on the line. With this arrangement tests were made to determine whether or not there were any effects upon the transmission of speech, due to superimposing high-frequency currents upon the battery telephone sets. With an operator at each end of the line; using the equipment in the regular commercial way, the direct current voltage and the alternating current voltage in series with it in the primary circuit of the transmitter were varied individually and relatively in a variety of ways, with the striking result that just at the point where the direct current voltage was decreased, so that no sounds were received, the line became absolutely silent, although the alternating voltage in the circuit was at its largest value, or, again, speech would reappear at the receiving station at the moment when sufficient direct current voltage was introduced to produce it, and the simultaneous presence of both the maximum direct voltage and maximum high-frequency voltage in a circuit produced exactly the same result as the maximum direct current voltage did alone. When, however, the high-frequency current in the local circuit was forced to a point which caused " burning " in the transmitter itself, then, and then only did the high-frequency current in any way interfere with the transmission.

By transferring this coil from the local circuit of the telephone set directly into the line itself, so that the high frequency oscillations would be superimposed upon the line beyond the iron cored induction coil of the telephone transmitter, it was not possible to detect the presence or absence of high-frequency currents.

As a test under severest conditions the effect was noted upon speech received at the same station at which the high frequency current is being impressed, for here are the attenuated telephonic currents at the receiving end of the telephone line, on which is superimposed a high-frequency current of vastly greater magnitude at the same point. No effects of any kind could be detected under these conditions. From the above experiments it appears that in any attempt at multiplex telephony by means of electric waves of ultra-sound frequencies superimposed upon the minute telephonic currents employed in battery transmission there is nothing to fear from disturbances of such currents upon the operation of the ordinary battery equipment.

Silent Earth Circuits

The electromagnetic constants of the apparatus employed in telegraphy and telephony over wire circuits are of the order of magnitude of microfarads and henrys, and since no attempt is made at tuning, these are constructed at present with no provision for continuously varying the units.

In wireless telegraphy and telephony these electromagnetic constants are of the order of magnitude one thousand times smaller, or are expressed in thousandths of microfarads and of henrys; furthermore, these forms of apparatus are provided with convenient means of continuously varying their values for tuning.

In the operation of providing tuning elements for earth connections there is at the same time afforded a certain means of eliminating any harmful disturbances from the earth, for the condensers employed for tuning to frequencies above audition possess an impedance to the frequencies involved in speech and also any disturbances from the earth, which effectively prevents the passage of any disturbance of audible frequency. These condensers offer a comparatively free passage to the electrical oscillations of the frequencies here being considered. When such earth connections are selectively tuned with the line to frequencies entirely above audition it is evident that no audible frequencies, either in the earth itself or from the line, can pass. Simple experiments proved the efficiency of this arrangement, and when the metallic telephone circuit, equipped with a standard local battery set, was connected to earth in the manner described, the operation of the battery set was perfectly quiet and equally good with and without such earth connections.

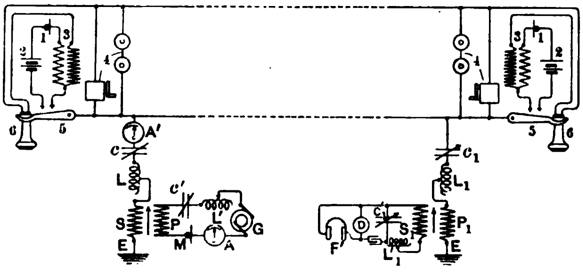


Fig. 4

The point was now reached where the road was clear for duplex telephony, and for this purpose the apparatus and methods employed in wireless telephony were applied to one of the wires of the metallic circuit as though it were an antenna. The actual arrangement of this circuit is shown in Fig. 4, in which G is the source of sustained high frequency oscillations; C' is the tuning condenser of the oscillatory circuit; L' is the tuning inductance of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A' is the ammeter in the line. At the receiving end of the line C_1 is the line tuning condenser; L_1 is the line tuning inductance; P_1 is the primary of the oscillation transformer; S_1 is the secondary of the oscillation transformer; L_1' is the tuning inductance in the oscillatory circuit; e_1' is the tuning condenser in the oscillatory circuit, between which and the telephone F' the detector D is operatively connected; E is the earth connection.

The local battery telephone sets are connected across the two line wires in the usual manner. In both sets 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

It was found that cross-talk was heard in the detector circuit from the battery transmitter at the transmitting end when the detector circuit alone was connected directly to earth from the line without any tuning coil or condenser. If, however, the tuning condenser was inserted, this cross-talk entirely disappeared, even though the tuning coil was not inserted. This is because the impedance of the small tuning condenser is large for telephonic frequencies, while the tuning coil impedance admits these telephonic frequencies. Both elements of tuning are required for selective absorption of energy, so that the high-frequency circuit is available as an additional telephonic circuit. With this arrangement talking in the transmitter of the high frequency side of the system was heard only in the detector and there was no cross-talk from the ordinary local battery circuit. Similarly, there was no effect of the high-frequency transmission on the local battery transmission, and the two telephonic messages were completely separated. Both circuits were entirely free from earth disturbances.

The volume of speech at the receiving end of the cable is greatly increased by simply inserting the transmitter in the dynamo circuit and operating this circuit at or near resonance. In addition, the coupling at both transmitting and receiving stations should be so designed as to permit adjustment for optimum.

The frequency used in this experiment was about 100,000 cycles per second. The talk on the regular battery circuit was of the usual high standard both ways, so that the only reason at this point why complete duplex-diplex telephony was not obtained was the fact that there was no high-frequency dynamo available at the laboratory. There is, however, available at this laboratory one of the latest forms of the high-frequency arc, and accordingly this was arranged with suitable electromagnetic constants to give a period of about 71,000 cycles per second, as measured by a standard wave meter such as is now commonly used in wireless telephony and telegraphy. This source of high-frequency electromotive force was induced upon the high frequency line wire in a similar manner to that described in the station at the Bureau of Standards, with the result that one of the wires of the twisted-pair was made to carry simultaneously the battery telephonic currents from the two transmitters, the high frequency oscillations of about 100,000 cycles per second, applied at the Bureau of Standards, and the high-frequency oscillations of about 71,000 cycles per second, applied at the laboratory. No influence from these conditions was perceptible upon the excellence of the battery transmission and reception of speech either way.

FIG. 5

DUPLEX TELEPHONY, USING METALLIC CIRCUIT

(A) BRIDGING ARRANGEMENT

The next experiments pertained to the standard metallic circuit as universally used on telephone toll lines in congested districts. The electric constants of this line have already been given.

The next step was to remove entirely the earth connections from the metallic circuit and superimpose both telephonic circuits upon the same pair of wires, as shown in Fig. 6, in which the high-frequency apparatus, shown diagrammatically in Fig. 5, is bridged across the line wires *A* and *A'*. *G* is the source of sustained high frequency oscillations; C_1 is the tuning condenser of the oscillatory circuit; L_1 is the tuning coil of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A_1 is the ammeter in the line. At the receiving end of the line, C' is the line tuning condenser; L' is the line tuning inductance; P' is the primary of the oscillation transformer; S' is the secondary of the oscillation transformer; L'' is the tuning inductance in the oscillatory circuit; C'' is the tuning condenser in the oscillatory circuit, between which and the telephone F the detector D is operatively connected.

The local battery telephone sets are connected across the line wires in the usual manner. In both sets, 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

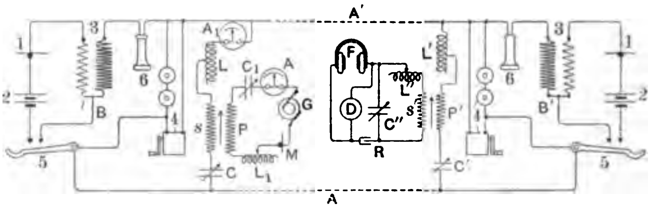


FIG. 6

Since the high frequency apparatus as commercially developed in the wireless telegraph art was used, each of the units was variable and had been previously carefully calibrated by reference to the standards of the Bureau of Standards. The coupling coils were of the design adapted for wireless telephony, the coefficient of coupling being adjustable between wide limits. It was therefore a matter of hours to run through a large number of experiments in which various combinations were tried.

The transmitters first tried were those of the microphone type inserted in the armature circuit of the dynamo and provided with water cooling when currents of several amperes were to be used.

It was soon found, however, that the efficiency of transmission of this cable line was so good for electric waves of these frequencies that a very small current, in the neighborhood of two milliamperes, sent into the line was amply sufficient for good speech at the receiving end about seven miles distant. No attempt was made to determine to what lower limit the transmission current could reach in this respect, but such small currents enabled the ordinary telephone transmitter to be used without any provision for cooling, especially when it was inserted in the line circuit, instead of in the armature circuit of the dynamo.

The telephone receivers were those regularly furnished for wireless telephony, ranging in resistance from 2,000 to 8,000 ohms.

Resonance. As was expected, the phenomena of resonance under the conditions which here obtained were very pronounced and highly consistent, since there is here a definite circuit free from the disturbances and variations inherent in radio telegraphy and telephony. In wireless telegraphy and telephony it is well known that within a few minutes transmission will drop off many fold from causes not entirely understood, and from diurnal variations and electrostatic disturbances, effective transmission is often prevented.

In general, the different circuits were tuned to resonance in the same manner, for the same purpose and with the same effect as in wireless telephony and telegraphy.

The line circuit itself was readily tuned to resonance for the particular frequency of the dynamo by noting the maximum reading of the hot wire ammeter A_1 in the line itself. This maximum is readily found by varying either the capacity C, or the inductance L, or both.

At the receiving end of the line, coil L' and the condenser C', as well as the coil L'' and the condenser C'', were tuned to give a maximum intensity of signals in the receiving telephone of the audion.

The audion, a detector of the so-called vacuum type, consists of an exhausted bulb containing (a) a tungsten filament maintained at incandescence by a current from a local battery of six volts and (b) two platinum electrodes insulated from the filament and from each other. To these electrodes, one of which is a platinum plate and the other a platinum grid, there are applied through the high resistance receivers about 35 to 45 volts from a local battery. The brilliancy of the filament is controlled by a small series rheostat, and the voltage applied to the insulated terminals by a local potentiometer.

The gases in the bulb, becoming ionized by contact with the glowing electrode, serve as a conductor of electricity, having a high unilateral conductivity. If the platinum wire grid is close to the hot filament and the plate at some greater distance, the direction of greater conductivity is from the plate through the gas by the ionic path to the grid, so that if the positive terminal of the telephone battery is applied at the plate terminal and the negative at the grid terminal, a sufficient current to operate the telephone will flow.

If the terminals of the condenser of a resonant receiving circuit are connected to the grid and to one terminal of the filament the high frequency e.m.f. impressed from this resonant circuit will cause a greater current to flow through the gas in one direction than in the other, as in the case of the direct-current potential applied through the telephone receiver. This rectifying effect will be reproduced in the telephone receivers, causing them to make audible the received signals.

By changing the coefficient of coupling or the potential across the audion, which is adjustable, or the amount of ionization of the gases in the tube by adjusting the current through the filament, or any combination of these, it was found that the receiving operator could bring out the speech to suit his particular fancy.

As stated above, the dynamo operated regularly at ranges from 100,000 cycles per second down to 20,000 cycles per second. It was therefore possible to try the effect of a comparatively wide range of frequencies in these experiments, covering three octaves, the inductances and capacities being chosen to correspond to each particular frequency. It was found that more energy was delivered over this particular type and length of circuit by using the lower frequencies of this range than the higher ones, although efficient results were easily obtained at any point.

The battery telephone side of the equipment was left absolutely intact, as it would be commercially used, and severe tests were made, employing four operators, to determine the efficiency of two simultaneous conversations over this same pair of wires.

The ringing circuit was operative both ways with no apparent effect on the high frequency telephone transmission. This ringing circuit develops a comparatively large alternating current flowing in the wire at about 30 cycles per second and at a voltage of many times that of either the high frequency or the battery side of the circuit.

Articulation tests, including music, numerals and other difficult combinations, gave satisfactory results, with no interference whatever between the two sides of the circuit.

By holding one telephone receiver to one ear and the other receiver to the other ear the receiving operator could hear two entirely different conversations simultaneously over the same pair of wires.

(B) SERIES ARRANGEMENT

A circuit was next made up with high frequency apparatus inserted directly in the line in series, instead of in the bridging arrangement shown in Fig. 5. The circuit used is shown diagrammatically in Fig. 7, in which *L* and *L'* are the secondary coils of the transmitter and receiver, respectively. *C* and *C'* represent variable condensers of the order of magnitude used in wireless telegraphy and serve as low impedance paths for the high-frequency oscillations, and at the same time prevent the short circuiting of the low-frequency battery telephone current. It was found that this arrangement gave apparently as good results as the bridging arrangement of the circuit.

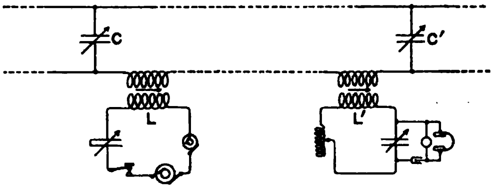


FIG. 7

III. DUPLEX-DIPLEX TELEGRAPHY

Having described in detail the experiments for obtaining the simultaneous transmission of two telephonic messages over a single circuit, it will be apparent that the problem of transmitting two telegraphic messages over the same circuit may be solved by methods and apparatus as far as the high frequency side of the circuit is concerned, which are practically identical with those described above.

In this connection the metallic circuit referred to was equipped with a standard Morse set for manual operation, and upon this circuit was superimposed an equipment for transmitting in one direction telegraphic messages by means of sustained high frequency oscillations, employing the telephone as the means for receiving the signals. The circuit used is shown diagrammatically in Fig. 8, in which, in the Morse set, there are shown between the line wire and the ground *G*, the line relay *S*, the key *K*, and the line battery *B*; and the local battery *b* and the sounder *s*; and in which, in the high frequency set, are similarly shown between the line wire and the ground *G* the tuning elements *C* and *L*; and at the transmitting end the oscillation transformer *T*, the primary of which is in circuit with the dynamo as a source of sustained oscillations, the telegraph key *K'*, the interrupter I and the tuning elements *C'* and *L'*, and at the receiving end the oscillation transformer *R* in the secondary circuit of which are included the usual tuning elements and operatively connected to them the detector and its telephone as a means of receiving the signals.

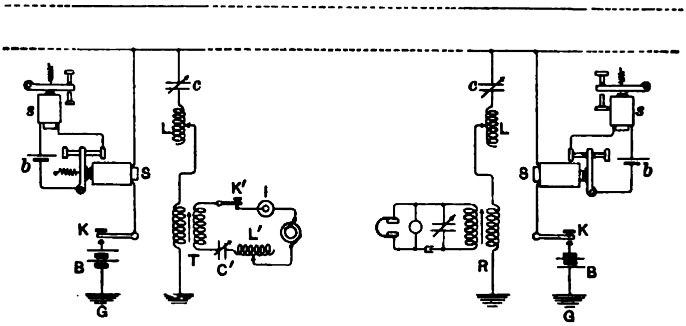


Fig. 8

As noted in the case of the preliminary local circuit tests, it was found that over this particular line it was not necessary to use a detector for electromagnetic waves, since enough energy was delivered to operate the telephone receiver by connecting it directly between the line and the earth.

The sound produced, however, was characteristically different in the two cases. With the detector the individual signals had the characteristic tone corresponding to the interrupter at the transmitting end of the line, whereas without the detector this tone was entirely absent, and a general dull sound, due to the resultant action of the wave-trains was heard. If, however, a telephone receiver was employed with a soft iron core, instead of a permanent magnet, no result was obtained with the limited power used on this line.

Although little mention of telegraphy by high-frequency electric waves has been made thus far, as a matter of fact it was found convenient during the experiments upon telephony actually to employ telegraphy as a quick and ready means of determining resonance between the circuits in each particular case.

When any particular arrangement was being employed the first steps were invariably to send simple Morse signals over the circuit until the operator at the distant end of the line reported maximum loudness in the receiving telephone, which indicated that the terminal apparatus with the line circuit was properly tuned. This being accomplished it was necessary only to throw a switch, to substitute for the automatic interrupter and telegraph key, the telephone transmitter, and the experiments could then proceed on telephony without any material change being made at the receiving station. Telephony and telegraphy thus proceeded hand in hand as a mere matter of convenience, and one of the practical advantages in the use of electric waves for transmitting intelligence is that the whole set-up of apparatus is practically the same for each and they can be used interchangeably over the same circuit.

Considering the Morse equipment, indicated in Fig. 8, the electromagnetic units involved are of the order of magnitude of microfarads and henrys, and the period of the interrupted direct current for Morse sending is not more than the equivalent of about 10 complete cycles per second, whereas in the high frequency side of the circuit the electromagnetic units are of the order of magnitude of thousandths of a microfarad and of thousandths of a henry and with frequencies not less than 2000 times greater than those involved in manual Morse sending. Furthermore, the ohmic resistance of the line which plays a prominent part in limiting the distance and speed of Morse working, is comparatively unimportant in the case of electric waves guided by wires. The operation of the line equipped as in Fig. 8 was perfectly satisfactory, there being no perceptible interference between the two messages in either direction.

Since the standard telegraph circuits of the world use a ground return, this same equipment was arranged to operate on one of the wires of the twisted-pair in the telephone cable as such a circuit with earth connections at each end, and its operation was equally successful.

Since it is a well known characteristic of high frequency apparatus used in tuned circuits that there shall be no iron involved in the circuit, it is evident that in cases where such a high-frequency current is to be superimposed upon a line comprising way-stations, where line relays are inserted directly in the circuit, it will be necessary and sufficient to shunt such way-stations by condensers of the order of magnitude of thousandths of a microfarad. Such condensers offer a comparatively free path for the high-frequency electric waves, but interpose a practical barrier to the Morse frequencies.

The same general statement can be made relative to any of the standard forms of low-frequency telegraphy over wires as now practiced, such as the polar duplex, the differential duplex, and the duplex-diplex employing alternating currents of low frequency and standard keys, relays and sounders.

Inserting a regular 150-ohm telegraph relay in series in the line cuts down the high frequency current to a small percentage of its original value, which indicates the marked influence of the presence of iron in such a circuit. Furthermore, it was noted that at 100,000 cycles the hysteresis of the iron core was so great that it became heated very perceptibly in a few moments.

Since a portion of the telegraph lines now used is still composed of iron wires, it would be expected that electric waves would be propagated over such wires less efficiently than over copper wires, although it is well known that electric waves penetrate only about one-thirteenth as deeply into soft iron for a given frequency as into copper, but this is modified by the fact that the iron in telegraph wires is not soft iron and in addition is galvanized.

IV. MEASUREMENTS OF ELECTRIC WAVES OF FREQUENCIES FROM 20,000 TO 100,000 CYCLES PER SECOND ON A STANDARD TELEPHONE CABLE LINE

In order to understand more fully the conditions for the successful transmission of electric waves along commercial telephone cable conductors, a preliminary study of this particular line has been made and the engineering data obtained is submitted.

In approaching the subject of these measurements, although the circuit involved is a wire circuit throughout, the method of treatment of the tests carried out has been that of wireless engineering, rather than the usual tests made upon wire circuits. The range of frequencies used overlaps at its upper limit those which already have been employed in long distance wireless telegraphy, and at the lower limit approaches those used in telephone tests near the upper limit of audibility.

The measurements have been confined to the simple case of the metallic circuit, and other circuits involving ground connections have not been investigated.

Resonance Curves

In order to determine in a general way the properties of this particular line independent of the receiving terminal apparatus, the first inquiry was directed to the construction of typical resonance curves in the cases, first, with the line open at the receiving end, and, second, with the line short-circuited at the receiving end, after which the modifications introduced by the presence of certain terminal apparatus were briefly investigated.

In order to indicate the general characteristics of these resonance curves as the frequency of the electric waves is varied, four particular frequencies were selected at approximately equal intervals from 95,000 to 36,500 cycles per second, and at each of these frequencies two curves were obtained, one with the line open and the other with the line short-circuited at the receiving end.

The generator was operated either from a dynamo source or from a storage battery, and under proper conditions it ran so regularly and the whole phenomena of resonance were so regular and orderly, that after a little practice the observations for each particular resonance curve could be taken as rapidly as the results could be recorded.

Continuing the readings for a complete curve back and forth from beginning to end several times indicated that under proper conditions the readings agree so well that there was no necessity for averaging observations for any particular point, and a single set of observations for a curve was as accurate as desired. It will be noted that in the observations given below the ammeter readings are equally spaced. This was convenient, since the variable tuning condenser could be easily adjusted to bring the ammeter needle to a division line on which it could be read more accurately than its position estimated in the uncalibrated space between. This removed any necessity for estimating divisions of the scale on the ammeter and contributed to accuracy.

The speed of the generator was determined by two methods: first, by observations with a tachometer upon a subsidiary shaft with a known ratio of rotation to that of the rotor, and, second, by readings from a wave meter accurately calibrated by reference to the standards of inductance and capacity of the

Bureau of Standards. The agreement between these was within the limits of error of observation.

Coefficient of Coupling

Since it was the desire to study the properties of the line itself independent of any reactions from the local oscillatory circuit of the dynamo, loose coupling was invariably employed between these two circuits.

In taking the observations the coefficient of coupling as dedefined by the expression

$$k=\frac{M}{\sqrt{L_1L_2}}$$

was made small by using a considerable separation between the primary and the secondary coils of the oscillation transformer,

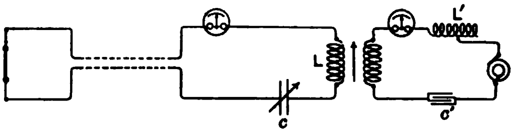


Fig. 9

and there is no indication in the curves taken of reactive effects of one circuit upon the other.

Stiffness Function, $\frac{L}{C}$

Since resonance may be obtained in an oscillatory circuit by an infinite number of combinations of L and C fulfilling the condition

$$L\,\omega=\frac{1}{C\,\omega}$$

or more generally for series circuits containing series coils and condensers

$$\omega\,\Sigma\,L=\frac{1}{\omega}\,\Sigma\,\frac{1}{C}$$

it is possible to select any suitable value of either of these quantities and tune by varying the other. In making these observations the tuning inductance was kept constant and the capacity element varied.

The stiffness function $\frac{L}{C}$ was not kept constant for the different frequencies at which the resonance curves were taken, but its value for each set of observations is given.

A convenient range of variable inductances and capacities, calibrated in absolute values, was available, and the designs of these were such as are commonly known in wireless telegraph practice as variometers and variable air condensers.

Hot wire ammeters were placed in both the primary and the secondary circuits, the one in the primary being used merely to indicate the constancy of the speed of the dynamo, for which purpose this circuit was adjusted to the steepest part of its resonance curve, at which point the ammeter reading is very sensitive to change in speed.

The typical circuit for obtaining this series of resonance curves is shown diagrammatically in Fig. 9. The value of the primary current was controlled by the tuning inductance L'; the capacity C' being constant.

RESONANCE CURVES AT $n = 93{,}800$, $\lambda = 3200$ METERS

CASE 1. LINE OPEN AT RECEIVING END

In Table I are given the observations for the resonance curves shown in Fig. 10.

The inductance L was constant and equal to 0.400 millihenry, and the first column gives the values of the condenser C for the corresponding values of the line current in milliamperes, shown in the last column of the table.

The construction of the curve is derived as follows:

For a simple series circuit at resonance

$$\lambda = \frac{v}{n} = 2\,\pi\,v\,\sqrt{L\,C} \qquad (1)$$

in which λ is the wave length, in cm., v is the velocity of light $= 3 \times 10^{10}$ cm. per second, $n =$ frequency in complete cycles per second; L is the sum of the inductances in the circuit in cm. and C is the total capacity in absolute electromagnetic units.

At resonance, the value of n, and consequently the value of λ is known, and is obtained from the frequency of the dynamo.

The value of the tuning condenser for the above conditions of resonance is known, and from this must first be determined its capacity reactance at this frequency. From the table it is seen that for resonance the capacity was equal to 0.00436 microfarad and the capacity reactance of this condenser at a frequency of 93,800 is equal to

$$\frac{1}{C\,\omega} = 389 \text{ ohms}$$

$$\text{or admittance} = 2.57 \times 10^{-3} \text{ mho.}$$

From the table it is seen that the tuning inductance is equal to 0.400 millihenry, and its inductance reactance at this frequency is equal to

$$L\,\omega = 236 \text{ ohms}$$

$$\text{or admittance} = 4.24 \times 10^{-3} \text{ mho.}$$

It appears, therefore, that of the tuning elements, the reactance of the condenser is greater by 153 ohms than that of the coil, from which it may be concluded that the line reactance at this frequency is of the nature of an inductance instead of a capacity, since at resonance the geometric sum of the reactances of the circuit is zero.

Here then is the necessary data to evaluate this equivalent inductance of the line at this frequency.

In equation (1) all the quantities are known except that part of L represented by the line, since the total inductance of the circuit is equal to the arithmetical sum of its parts, provided there is no mutual induction between any of these parts, which condition obtained in this case.

From equation (1):

$$\frac{v}{n} = 2\,\pi\,v\,\sqrt{(L+L')\,C} \tag{2}$$

in which L' is the quantity to be determined. From which

$$L' = \frac{\frac{1}{n^2} - 4\,\pi^2\,C\,L}{4\,\pi^2\,C} = \frac{1}{4\,\pi^2\,n^2\,C} - L \tag{3}$$

Substituting the known values in (3)

$$L' = 260{,}000 \text{ cm.}$$
$$= 0.260 \text{ millihenry.}$$

TABLE I

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 93,800 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00183	0.400	——	2070	145,000	50
0.00210	"	——	2220	135,000	60
0.00230	"	——	2320	129,000	70
0.00248	"	——	2410	124,000	80
0.00260	"	——	2470	121,000	90
0.00266	"	——	2500	120,000	100
0.00280	"	——	2570	117,000	110
0.00288	"	——	2600	115,000	120
0.00301	"	——	2660	113,000	130
0.00312	"	——	2710	111,000	140
0.00321	"	——	2750	109,000	150
0.00329	"	——	2780	108,000	160
0.00339	"	——	2820	106,000	170
0.00351	"	——	2870	105,000	180
0.00363	"	——	2920	103,000	190
0.00373	"	——	2960	101,000	200
0.00391	"	——	3030	99,000	210
0.00436	"	0.260	3200	93,800	215
0.00464	"	——	3300	90,900	200
0.00511	"	——	3470	86,500	190
0.00543	"	——	3570	84,000	180
0.00571	"	——	3660	82,000	170
0.00629	"	——	3850	77,900	160
0.00668	"	——	3960	75,800	150
0.00713	"	——	4100	73,200	140
0.00768	"	——	4250	70,600	130
0.00863	"	——	4500	66,700	120
0.00914	"	——	4630	64,800	110
0.01085	"	——	5050	59,400	100
0.01335	"	——	5600	53,600	82

For tuning elements at resonance:

$$\frac{L}{C} = 0.917 \times 10^{5} \text{ for practical units.}$$

$$= 0.917 \times 10^{23} \text{ for absolute electromagnetic units.}$$

It was desirable to measure the value of the effective voltage being impressed upon the line itself at the transmitting end, but no electrostatic voltmeter is available which will read directly small values for alternating electromotive forces.

The lowest reading of the electrostatic voltmeter available was 40, and this instrument when placed directly across the line gave no perceptible reading. It is possible, however, to estimate closely the voltage used, for since the ohmic resistance of the secondary coil in the line circuit was only a fraction of an ohm, the impedance of the coil at this frequency can be taken as practically 180° from that of the condenser without sensible error. The voltage drop across the coil at resonance is equal to

$$L\,\omega\,I = 236 \times 0.215 = 50.7 \text{ volts.}$$

The voltage drop across the condenser is equal to

$$\frac{I}{C\,\omega} = 389 \times 0.215 = 83.6 \text{ volts.}$$

Therefore, the voltage being impressed upon the line at resonance is

$$83.6 - 50.7 = 33 \text{ volts approximately.}$$

To determine other points of the resonance curve, there are these relations between the solution at resonance and any other solution at dissonance.

$$\lambda = \frac{v}{n} = 2\,\pi\,v\,\sqrt{L\,C}$$

$$\lambda_1 = \frac{v}{n_1} = 2\,\pi\,v\,\sqrt{L_1\,C_1}$$

$$\frac{n_1}{n} = \frac{\sqrt{L\,C}}{\sqrt{L_1 C_1}}$$

$$n_1 = n\sqrt{\frac{L\,C}{L_1 C_1}}$$

Since $L = L_1$ throughout a set of observations

$$n_1 = n\sqrt{\frac{C}{C_1}} = \frac{k}{\sqrt{C_1}}$$

where $k = n\,\sqrt{C}$ = constant and C_1 is the observed value given in column one of Table 1.

Having determined in this manner the value of the frequencies for each of the points of dissonance given in the table, the corresponding wave-lengths in meters in the fourth column were derived.

The graphs of these curves are shown in Fig. 10.

It is observed that the line current-frequency curve is not symmetrical, but is steeper on the side of the higher frequencies.

The line current-wave length curve is steeper on the side of the shorter wave-length:

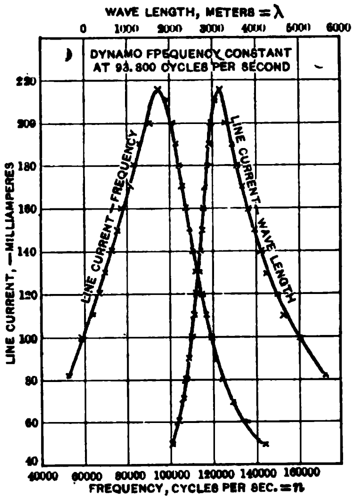


Fig. 10.—Resonance curves at transmitting end, telephone cable line, receiving end open

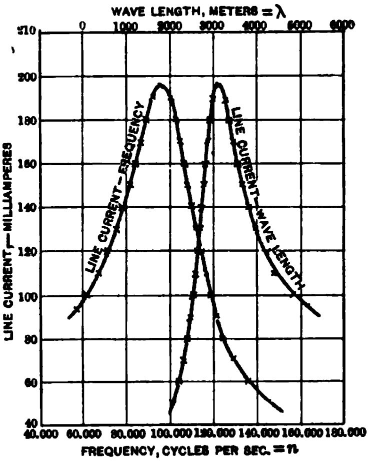


Fig. 11.—Resonance curves at transmitting end, telephone cable line, receiving end short-circuited. Dynamo frequency constant at 95,200 cycles per second

CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

With the dynamo frequency constant at 95,200 a similar set of observations was taken for the case of the receiving end of the line short-circuited, and these observations are exhibited in Table II.

The graphs for the line current-frequency and line current-wave length are shown in Fig. 11.

RESONANCE CURVES AT $n = 73{,}000$ $\lambda = 4110$ METERS

CASE 1. LINE OPEN AT RECEIVING END

In Table III are given the observations for the two curves shown in Fig. 12.

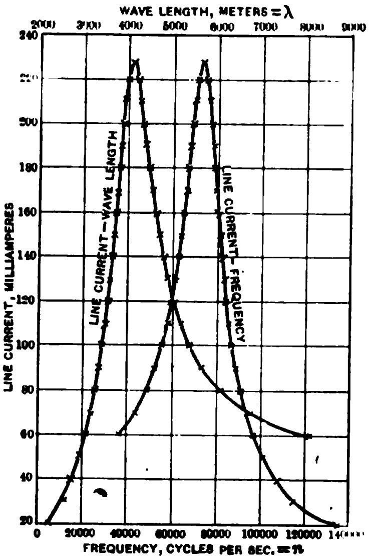


FIG. 12.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 73,000 cycles per second

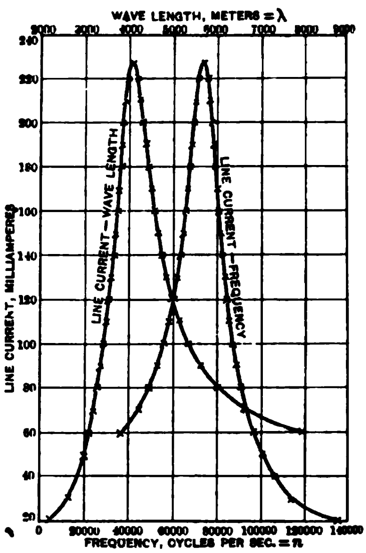


FIG. 13.—Resonance curves at transmitting end, telephone cable line, receiving end closed. Dynamo frequency constant at 73,000 cycles per second

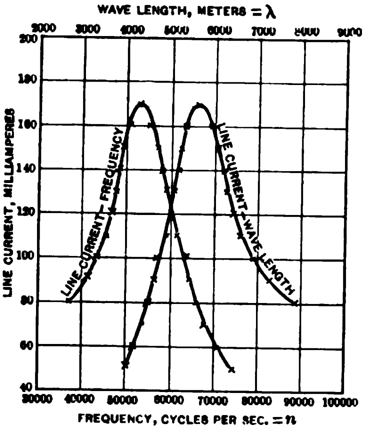


FIG. 14.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 53,000 cycles per second.

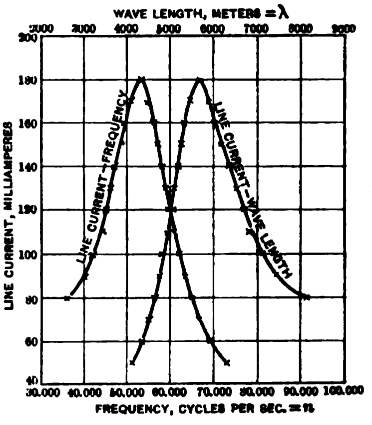


FIG. 15.—Resonance curves at transmitting end, telephone cable line, receiving end short-circuited. Dynamo frequency constant at 53,000 cycles per second.

CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

In Table IV are given the observations for the two resonance curves shown in Fig. 13.

TABLE II

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 95,200 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milliamperes
0.00171	0.400	——	2060	146,000	50
0.00195	"	——	2200	136,000	60
0.00217	"	——	2320	129,000	70
0.00238	"	——	2430	123,000	80
0.00246	"	——	2470	121,000	90
0.00258	"	——	2530	119,000	100
0.00267	"	——	2570	117,000	110
0.00279	"	——	2630	114,000	120
0.00287	"	——	2670	112,000	130
0.00297	"	——	2710	111,000	140
0.00310	"	——	2770	108,000	150
0.00322	"	——	2830	106,000	160
0.00333	"	——	2870	105,000	170
0.00342	"	——	2910	103,000	180
0.00356	"	——	2970	101,000	190
0.00400	"	0.295	3150	95,200	196
0.00432	"	——	3270	91,700	190
0.00457	"	——	3370	89,000	180
0.00485	"	——	3470	86,500	170
0.00510	"	——	3560	84,300	160
0.00534	"	——	3640	82,400	150
0.00581	"	——	3800	78,900	140
0.00626	"	——	3940	76,100	130
0.00718	"	——	4220	71,100	120
0.00784	"	——	4410	68,000	110
0.00950	"	——	4850	61,900	100
0.01085	"	——	5190	57,800	94

For tuning elements at resonance:

$\frac{L}{C} = 1.0 \times 10^{5}$ **for practical units.**

$= 1.0 \times 10^{23}$ **for absolute electromagnetic units.**

RESONANCE CURVES AT $n = 53{,}000$, $\lambda = 5660$ METERS

CASE 1. LINE OPEN AT RECEIVING END

In Table V are given the observations for the two curves shown in Fig. 14.

TABLE III

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 73,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00147	0.818	——	2210	136,000	20
0.00208	"	——	2630	114,000	30
0.00235	"	——	2800	107,000	40
0.00268	"	——	2990	100,000	50
0.00289	"	——	3100	96,800	60
0.00309	"	——	3210	93,500	70
0.00324	"	——	3290	91,200	80
0.00343	"	——	3380	88,800	90
0.00357	"	——	3450	87,000	100
0.00367	"	——	3500	85,700	110
0.00379	"	——	3560	84,300	120
0.00387	"	——	3590	83,600	130
0.00398	"	——	3640	82,400	140
0.00407	"	——	3680	81,500	150
0.00416	"	——	3730	80,400	160
0.00423	"	——	3760	79,800	170
0.00435	"	——	3810	78,700	180
0.00444	"	——	3850	77,900	190
0.00455	"	——	3890	77,100	200
0.00464	"	——	3930	76,300	210
0.00478	"	——	3990	75,200	220
0.00506	"	0.121	4110	73,000	227
0.00527	"	——	4190	71,600	220
0.00547	"	——	4270	70,300	210
0.00563	"	——	4330	69,300	200
0.00577	"	——	4390	68,300	190
0.00594	"	——	4450	67,400	180
0.00611	"	——	4510	66,500	170
0.00629	"	——	4580	65,500	160
0.00651	"	——	4660	64,400	150
0.00675	"	——	4740	63,300	140
0.00707	"	——	4850	61,900	130
0.00741	"	——	4970	60,400	120
0.00789	"	——	5130	58,500	110
0.00858	"	——	5350	56,100	100
0.00950	"	——	5630	53,300	90
0.01105	"	——	6070	49,400	80
0.01346	"	——	6700	44,800	70
0.01905	"	——	7970	37,600	60

For tuning elements at resonance:

$$\frac{L}{C} = 1.62 \times 10^{5} \text{ for practical units.}$$

$$= 1.62 \times 10^{23} \text{ for absolute electromagnetic units.}$$

CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

In Table VI are given the observations for the two resonance curves shown in Fig. 15.

RESONANCE CURVES AT $n=38{,}500$ $\lambda=7790$ METERS

CASE 1. LINE OPEN AT RECEIVING END

In Table VII are given the observations for the two curves shown in Fig. 16.

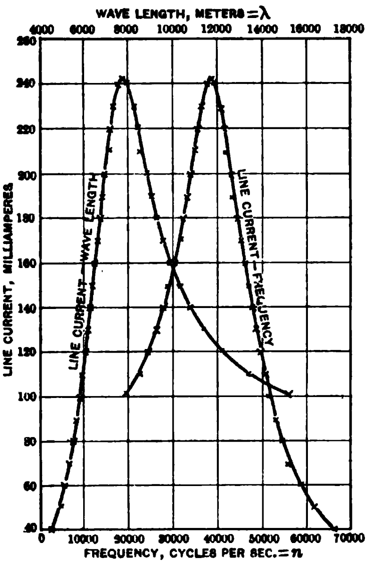


FIG. 16.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 38,000 cycles per second.

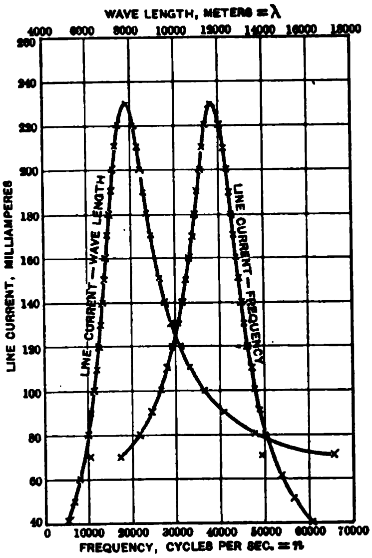


FIG. 17.—Resonance curves at transmitting end, telephone cable line, receiving end closed. Dynamo frequency constant at 38,000 cycles per second

CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

In Table VIII are given the observations for the two resonance curves shown in Fig. 17.

SELECTIVITY CURVES

The series of resonance curves given above are the usual types constructed in the study of wireless antennæ, but in order to interpret them from an engineering point of view, it is more valuable to plot them as selectivity curves, in which the line current is plotted as a function of the frequency.

TABLE IV

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 73,000 complete cycles per second

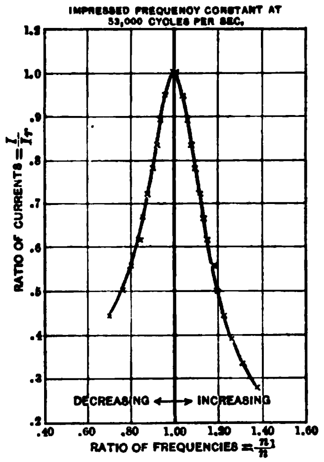
Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milliamperes
0.00144	0.818	——	2230	134,000	20
0.00197	"	——	2600	115,000	30
0.00227	"	——	2790	108,000	40
0.00253	"	——	2950	102,000	50
0.00281	"	——	3110	96,500	60
0.00298	"	——	3200	93,800	70
0.00315	"	——	3290	91,200	80
0.00332	"	——	3380	88,800	90
0.00345	"	——	3450	87,000	100
0.00358	"	——	3510	85,500	110
0.00369	"	——	3560	84,300	120
0.00376	"	——	3600	83,300	130
0.00387	"	——	3650	82,200	140
0.00396	"	——	3690	81,300	150
0.00404	"	——	3730	80,400	160
0.00415	"	——	3780	79,400	170
0.00425	"	——	3820	78,500	180
0.00430	"	——	3850	77,900	190
0.00439	"	——	3890	77,100	200
0.00452	"	——	3940	76,100	210
0.00464	"	——	4000	75,000	220
0.00491	"	0.150	4110	73,000	227
0.00515	"	——	4210	71,300	220
0.00533	"	——	4280	70,100	210
0.00551	"	——	4350	69,000	200
0.00566	"	——	4410	68,000	190
0.00585	"	——	4490	66,800	180
0.00600	"	——	4540	66,100	170
0.00620	"	——	4620	64,900	160
0.00640	"	——	4690	64,000	150
0.00666	"	——	4790	62,600	140
0.00697	"	——	4900	61,200	130
0.00731	"	——	5020	59,800	120
0.00775	"	——	5160	58,100	110
0.00848	"	——	5400	55,600	100
0.00940	"	——	5690	52,700	90
0.01087	"	——	6120	49,000	80
0.01332	"	——	6770	44,300	70
0.01905	"	——	8100	37,000	60

For tuning elements at resonance·

$$\frac{L}{C} = 1.67 \times 10^5 \text{ for practical units.}$$

$$= 1.67 \times 10^{23} \text{ for absolute electromagnetic units.}$$

In order to be able to read directly the percentage drop in current from the value at resonance taken as unity, for any given percentage departure from the frequency at resonance, also taken as unity, it is necessary only to plot ordinates in terms of $\frac{I}{I_r}$, in which I is any particular value of the current corresponding to the frequency n_1, and I_r is the value of the current at resonance; and abscissas in terms of $\frac{n_1}{n}$ in which n_1 is the frequency of the line circuit at any point of dissonance, and n is the frequency at resonance.



I_r = Line current at resonance
I = Line current
n = Frequency at resonance
n_1 = Frequency of line circuit tuned to given dissonance

FIG. 18.—Selectivity curve of telephone cable line, receiving end short-circuited

As an example, in the case of $n = 53{,}000$, Table IX has been computed. The graph of this curve is shown in Fig. 18.

It appears from the inspection of this curve that it is not symmetrical with respect to the ordinate corresponding to resonance. The slope of the curve is steeper for increasing frequencies than for decreasing frequencies. It is possible to read off directly from this curve the percentage change in the line current from resonance for any given percentage change in frequency from resonance. For instance, it is seen that for 10 per cent decrease in the frequency of the line circuit, the current has fallen to 79 per cent of its value at resonance, and at 30 per cent *decrease* in frequency of the line circuit, the current has fallen to 44 per cent of its value at resonance, whereas at 30 per cent increase in frequency of the line circuit the current has fallen to 34 per cent of its value at resonance, which is considerably lower; in other words, the line current is more sensitive to changes on the side of increasing frequencies than on the side of decreasing frequencies in the case of impressed constant frequency of the dynamo of 53,000 cycles per second.

The current is seen to be reduced to one-half its value at resonance for a 24 per cent reduction in frequency, and to the same amount for 20 per cent increase of frequency.

A curve of this kind makes it possible to predict that terminal apparatus could be inserted in this line at the receiving end, provided it was in the nature of ohmic resistance, and that there would be no interference between several of such instruments operated at different frequencies, provided the interval between the frequencies of each of the different receiving sets was greater than 44 per cent, and that each receiving apparatus was not rendered inoperative by the presence of a stray current of 50 per cent of its normal operating value. It should be re-

TABLE V

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 53,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent capacity of the line in microfarads computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00452	1.036	—	4040	74,300	50
0.00494	"	—	4220	71,100	60
0.00542	"	—	4420	67,900	70
0.00570	"	—	4530	66,200	80
0.00600	"	—	4640	64,700	90
0.00624	"	—	4730	63,400	100
0.00672	"	—	4910	61,100	110
0.00700	"	—	5000	60,000	120
0.00723	"	—	5080	59,100	130
0.00747	"	—	5160	58,100	140
0.00777	"	—	5260	57,000	150
0.00816	"	—	5390	55,700	160
0.00902	"	0.251	5660	53,000	170
0.00988	"	—	5910	50,800	160
0.01036	"	—	6050	49,600	150
0.01086	"	—	6190	48,500	140
0.01115	"	—	6260	47,900	130
0.01172	"	—	6420	46,700	120
0.01232	"	—	6570	45,700	110
0.01355	"	—	6880	43,600	100
0.01522	"	—	7260	41,300	90
0.01860	"	—	7980	37,600	80

For tuning elements at resonance:

$\frac{L}{C} = 1.15 \times 10^{5}$ **for practical units.**

$= 1.15 \times 10^{23}$ **for absolute electromagnetic units.**

membered that this interpretation is from conditions controllable at the transmitting end only, and provides for no selective tuning whatever of the apparatus at the receiving end. In other words the curve given shows the selectivity of the line itself.

TABLE VI

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 53,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent capacity of the line in microfarads computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00469	1.036	——	4120	72,800	50
0.00516	"	——	4320	69,400	60
0.00564	"	——	4510	66,500	70
0.00598	"	——	4640	64,700	80
0.00624	"	——	4740	63,300	90
0.00642	"	——	4800	62,500	100
0.00682	"	——	4950	60,600	110
0.00708	"	——	5040	59,500	120
0.00729	"	——	5110	58,700	130
0.00749	"	——	5180	57,900	140
0.00777	"	——	5270	56,900	150
0.00796	"	——	5330	56,300	160
0.00838	"	——	5470	54,800	170
0.00900	"	0.265	5660	53,000	180
0.00981	"	——	5900	50,800	170
0.01030	"	——	6040	49,700	160
0.01068	"	——	6150	48,800	150
0.01138	"	——	6340	47,300	140
0.01202	"	——	6510	46,100	130
0.01269	"	——	6680	44,900	120
0.01318	"	——	6800	44,100	110
0.01450	"	——	7110	42,200	100
0.01587	"	——	7420	40,400	90
0.01932	"	——	8140	36,900	80

For tuning elements at resonance:

$\frac{L}{C} = 1.15 \times 10^{5}$ for practical units.

$= 1.15 \times 10^{23}$ for absolute electromagnetic units.

ELECTRICAL DIMENSIONS OF TUNING ELEMENTS

For the range of frequencies involved in these experiments the values of the standard variable air condensers and variometers which are at present employed in wireless telegraph practice, could better be made of larger electrical dimensions in order to be better adapted to the frequencies here considered.

TABLE VII

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 38,500 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00215	0.818	——	3540	84,700	20
0.00298	"	——	4160	72,100	30
0.00347	"	——	4490	66,800	40
0.00407	"	——	4860	61,700	50
0.00450	"	——	5120	58,600	60
0.00495	"	——	5360	56,000	70
0.00525	"	——	5520	54,300	80
0.00551	"	——	5660	53,000	90
0.00589	"	——	5850	51,300	100
0.00600	"	——	5900	50,800	110
0.00631	"	——	6060	49,500	120
0.00655	"	——	6170	48,600	130
0.00681	"	——	6290	47,700	140
0.00700	"	——	6380	47,000	150
0.00730	"	——	6520	46,000	160
0.00756	"	——	6630	45,200	170
0.00780	"	——	6740	44,500	180
0.00809	"	——	6860	43,700	190
0.00834	"	——	6960	43,100	200
0.00877	"	——	7140	42,000	210
0.00894	"	——	7210	41,600	220
0.00923	"	——	7320	41,000	230
0.01015	"	——	7680	39,100	240
0.01044	"	0.818	7790	38,500	241.5
0.01076	"	——	7910	37,900	240
0.01170	"	——	8250	36,400	230
0.01220	"	——	8420	35,600	220
0.01268	"	——	8590	34,900	210
0.01332	"	——	8800	34,100	200
0.01397	"	——	9020	33,300	190
0.01484	"	——	9290	32,300	180
0.01554	"	——	9500	31,600	170
0.01687	"	——	9910	30,300	160
0.01844	"	——	10400	28,800	150
0.02005	"	——	10800	27,800	140
0.02247	"	——	11400	26,300	130
0.02541	"	——	12200	24,600	120
0.03091	"	——	13400	22,400	110
0.03978	"	——	15200	19,700	101.5

For tuning elements at resonance:

$\frac{L}{C}=0.784\times10^{5}$ **for practical units.**

$=0.784\times10^{23}$ **for absolute electromagnetic units.**

TABLE VIII
OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 38,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00217	0.818	——	3990	75,200	20
0.00291	"	——	4620	64,900	30
0.00337	"	——	4970	60,440	40
0.00384	"	——	5300	56,600	50
0.00428	"	——	5600	53,600	60
0.00507	"	——	6090	49,300	70
0.00491	"	——	5990	50,100	80
0.00516	"	——	6150	48,800	90
0.00539	"	——	6280	47,800	100
0.00559	"	——	6400	46,900	110
0.00581	"	——	6520	46,000	120
0.00597	"	——	6610	45,400	130
0.00601	"	——	6630	45,200	140
0.00630	"	——	6790	44,200	150
0.00649	"	——	6890	43,500	160
0.00661	"	——	6960	43,100	170
0.00679	"	——	7050	42,600	180
0.00694	"	——	7130	42,100	190
0.00714	"	——	7230	41,500	200
0.00733	"	——	7320	41,000	210
0.00758	"	——	7450	40,300	220
0.00850	"	1.26	7890	38,000	230
0.00894	"	——	8090	37,100	220
0.00935	"	——	8270	36,300	210
0.00961	"	——	8380	35,800	200
0.00995	"	——	8540	35,100	190
0.01031	"	——	8690	34,500	180
0.01070	"	——	8850	33,900	170
0.01101	"	——	8980	33,400	160
0.01175	"	——	9280	32,300	150
0.01234	"	——	9500	31,600	140
0.01318	"	——	9820	30,500	130
0.01412	"	——	10200	29,400	120
0.01537	"	——	10600	28,300	110
0.01737	"	——	11300	26,500	100
0.02033	"	——	12200	24,600	90
0.02530	"	——	13600	22,000	80
0.03978	"	——	17100	17,500	70

For tuning elements at resonance:

$$\frac{L}{C}=0.963\times10^{5}\text{ for practical units.}$$

$$=0.963\times10^{23}\text{ for absolute electromagnetic units.}$$

It is noted from the tables submitted that capacities as large as hundredths of a microfarad were at times used, and in order to secure these it was necessary to join several of the air condensers of wireless telegraph pattern in parallel, adding their results. In like manner the inductances used were as high as three millihenrys in some cases. Fortunately, capacities and inductances can be easily constructed which at the same time preserve the continuously variable feature necessary for tuning purposes, and may have also compact physical dimensions; in fact in suitable designs for these frequencies these tuning elements may be even smaller and more compact than they now are for wireless telegraph practice. This is for the reason that

TABLE IX

DATA FOR SELECTIVITY CURVE OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 53,000 complete cycles per second

n_1	I	$\frac{n_1}{n}$	$\frac{I}{I_r}$
72,800	50	1.374	0.278
69,400	60	1.310	0.333
66,500	70	1.255	0.388
64,700	80	1.221	0.444
63,300	90	1.194	0.500
62,500	100	1.180	0.556
60,600	110	1.144	0.611
59,500	120	1.123	0.667
58,700	130	1.108	0.722
57,900	140	1.092	0.778
56,900	150	1.074	0.833
56,300	160	1.062	0.889
54,800	170	1.034	0.945
53,000	180	1.000	1.000
50,800	170	0.958	0.945
49,700	160	0.938	0.889
48,800	150	0.921	0.833
47,300	140	0.892	0.778
46,100	130	0.870	0.722
44,900	120	0.847	0.667
44,100	110	0.832	0.611
42,200	100	0.796	0.556
40,400	90	0.762	0.500
36,900	80	0.698	0.444

n_1 Frequency of line circuit tuned to given dissonance with generator frequency.

I Measured line current at frequency n_1, in milliamperes.

n Impressed frequency of generator, constant at 53,000 cycles per second.

I_r Maximum current in line circuit, tuned to resonance with generator frequency, 180 milliamperes.

in the case of electric waves impressed upon wires there are no high voltages such as are required in apparatus using an antenna. Furthermore, by properly designing inductances in accordance with the fundamental formulas laid down by Maxwell, it is evident that variometers suitable for this range of frequencies impressed upon wire circuits may be made extremely small and compact.

It should be noted that throughout these experiments not a single piece of new apparatus was designed or constructed, but the conventional apparatus as now employed in wireless telegraph engineering was adopted as a whole, although, as stated above, this apparatus could be very materially improved in the line of compactness of design for this range of frequencies.

Since no cases of high voltage were required at the transmitting end of the line, the same form of apparatus was used interchangeably for transmitting and receiving, whereas in wireless practice the transmitting antennæ coils and condensers are very large in comparison with those used for receiving.

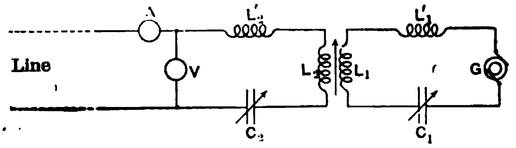


FIG. 19

TRANSMITTING IMPEDANCE AT RESONANCE BY THE AMMETER-VOLTMETER METHOD

To determine the general character of the effective impedance of this line as the frequency is changed, measurements were made of the transmitting current and voltage as the frequency was varied from about 23,000 to 90,000 cycles per second. The circuit is shown in Fig. 19 and the data obtained is given in Table X which is shown graphically in Fig. 20. In taking these measurements, loose coupling was used and the tuning elements adjusted to resonance in each case. The voltmeter used was of the hot wire type of comparatively high resistance, and the ammeter was of the hot wire type of low resistance. At resonance $I=\frac{E}{Z}$ or $Z=\frac{E}{I}$ where E and I are the measurements given above, from which Z in columns 4 and 7 Table X has been derived. The curves Fig. 20 indicate a minimum effective impedance of about 87 ohms at a frequency of about 59,000, the curves being nearly symmetrical on either side of this frequency.

Attempts were made to make similar measurements for the line conductively connected to the generator instead of inductively connected as above and working to constant voltage at different frequencies. In such cases the reaction between the resonant circuit of the line and the conductively connected circuit of the generator armature, was so marked and so sensitive to variation of frequency at resonance that it was found extremely difficult to make consistent measurements under these conditions. The marked superiority of loose inductive coupling between the line circuit and the generator enabled a study to be made of the line circuit *per se* without involving any reactive influence from the generator source.

TABLE X

DATA FOR TRANSMITTING END IMPEDANCE AT RESONANCE OF TELEPHONE CABLE LINE, RECEIVING END OPEN AND SHORT CIRCUITED, AT DIFFERENT FREQUENCIES

Cycles per second	Line open			Line short-circuited		
	Volts	Amperes	Ohms	Volts	Amperes	Ohms
23,000	22.2	0.108	206	22.6	0.106	213
35,000	16.1	0.112	144	16.2	0.116	140
47,000	16.0	0.154	104	16.0	0.153	105
63,000	15.8	0.178	89	15.8	0.180	88
75,000	16.3	0.148	110	16.2	0.148	109
90,000	23.8	0.138	172	23.5	0.138	170

It is noteworthy that with this cable line it was not possible to detect with certainty the reactive influence of opening or closing the distant end of the line upon the transmitting voltmeter and ammeter readings, and, as noted above, the resonant curves at the transmitting end are practically the same for the distant end open or closed.

The presence in this line of two pairs of inductive heat coils at fixed points undoubtedly is sufficient to cause at least partial reflections of the waves being propagated along the line. These heat coils, as stated above, each had a measured inductance of 4400 cms. at 70,000 cycles.

Resonance Curve at Receiving End

In the series of resonance curves, which has already been given, the observations were taken at the transmitting end of the cable line and no attempt at tuning was made at the receiving end of the line, it being the object to study first the line *per se* without terminal apparatus. The effects, however, of introducing tuning elements across the line at the receiving end are strikingly shown in Fig. 21, the data for which is given in Table XI. In taking these observations a frequency of 40,000 was selected as fairly representative.

At the transmitting end of the line the current and frequency were kept constant throughout, and at the receiving end of the line only the capacity element of the tuning apparatus was varied, which caused a rise and fall of the received current, as shown in Fig. 21.

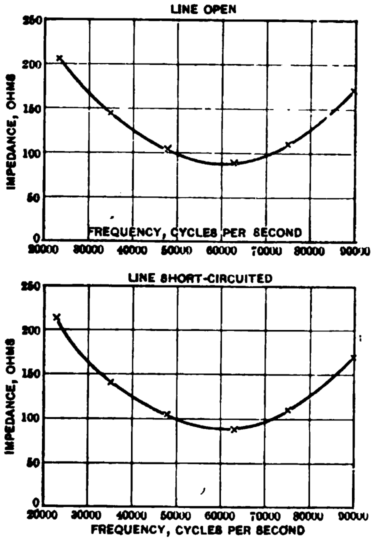


FIG. 20.—Impedance-frequency curve at resonance, transmitting end of telephone cable line

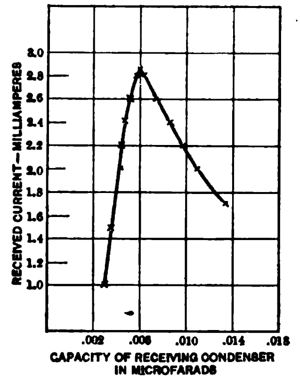


FIG. 21.—Resonance curve at receiving end of telephone cable line. Transmitting current constant at 200 milliamperes and at 40,000 cycles

The inductance element of the tuning apparatus at the receiving end was kept constant throughout the experiment, so that the variables which are plotted in this curve are the actual observations taken and therefore represent exact conditions with no supposition as to derived results. It is noted that the magnitude of received current in this case can be easily multiplied nearly three times by simply adjusting the variable condenser at the receiving end, in a receiver arrangement selected at random.

ATTENUATION CURVE

To determine quantitatively the influence of variation of frequency upon the attenuation of the current transmitted over this telephone line, the data given in Table XII were obtained, the curve for which is shown in Fig. 22.

In this experiment the transmitting current was kept constant at 240 milliamperes, the only thing varied being the frequency of the alternator.

At the receiving end the telephone line was short-circuited through a Duddell thermo-ammeter, which is practically non-inductive with a resistance of 171 ohms. The frequency was varied between 30,000 and 90,000 cycles per second, and observations were taken at intervals of 10,000 cycles per second. The curve shows very strikingly the attenuation of the transmitted current as the frequency is increased. The values of the received current at 80,000 and 90,000, being about as small as could be read on the particular ammeter used, are not as accurate as the other readings, and this is indicated by the dotted part of the curve.

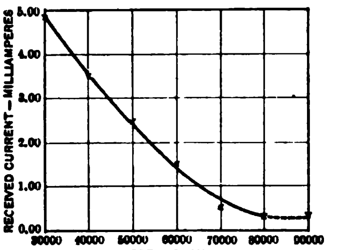


FIG. 22.–Attenuation-frequency curve at receiving end of telephone cable line, short-circuited though. Duddell thermo-ammeter of 171 ohms, transmitting current constant at 240 milliamperes

SUMMARY

Radio-telegraphy has no competitor as a means of transmitting intelligence between ships at sea and between ships and shore stations, and on land it is also unique in its usefulness in reaching isolated districts and otherwise inaccessible points. To what extent it may be also developed to furnish practical intercommunication according to the high standard now enjoyed in thickly populated districts, it is not attempted to predict.

The foregoing experiments indicate that either the existing wire system, or additional wires for the purpose may be utilized for the efficient transmission of telephonic and telegraphic messages, and the former without interfering with the existing telephone traffic on these wires.

The fact that each of the circuits created by the use of superimposed high-frequency methods is both a telephone and a telegraph circuit interchangeably, makes it possible to offer to the public a new type of service, which it is believed, will offer many advantages to the commercial world. This type of circuit should be particularly applicable to press association service, railroad service, and leased wire service of all kinds.

TABLE XI
RESONANCE CURVE AT RECEIVING END OF TELEPHONE CABLE LINE. TRANSMITTING CURRENT CONSTANT AT 200 MILLIAMPERES AND 40,000 CYCLES

Receiving capacity in microfarads in series with constant inductance	Received current in milliamperes
0.00292	1
0.00354	1.5
0.00422	2
0.00442	2.2
0.00470	2.4
0.00508	2.6
0.00579	2.8
0.00606	2.83
0.00622	2.8
0.00748	2.6
0.00870	2.4
0.00972	2.2
0.01097	2.0
0.01337	1.7

TABLE XII
DATA FOR ATTENUATION-FREQUENCY CURVE AT RECEIVING END OF TELEPHONE CABLE LINE, SHORT-CIRCUITED THROUGH DUDDELL THERMO-AMMETER OF 171 OHMS, TRANSMITTING CURRENT CONSTANT AT 240 MILLIAMPERES

Transmitting current in milliamperes	Received current in milliamperes	Frequency
240	4.85	30,000
"	3.50	40,000
"	2.45	50,000
"	1.5	60,000
"	0.5	70,000
"	0.3	80,000
"	0.3	90,000

The experiments described should not be interpreted as in any way indicating limitations to radio-telegraphy and telephony in the future, for their present rapid development gives justification for great prospect for the future. It is rather considered that the whole system of intercommunication, including both wire methods and wireless methods, will grow apace, and as each advance is made in either of these it will create new demands and standards for still further development. We need more wireless telegraphy everywhere, and not less do we need more wire telegraphy and telephony everywhere, and, again, more submarine cables. The number of submarine cables connecting Europe with America could be increased many times and all of them kept fully occupied, provided the traffic were properly classified to enable some of the enormous business which is now carried on by mail to be transferred to the quicker and more efficient cablegram letter. That time will surely come when the methods of electrical inter-communication will have been so developed and multiplied that the people of the different countries of the world may become real neighbors.

Accustomed to the methods of transmitting energy for power purposes by means of wire, it is a matter of wonder that enough energy can be delivered at a receiving antenna from a transmitting point thousands of miles distant to operate successfully receiving devices. The value of a metallic wire guide for the energy of the electric waves is strikingly shown in the above experiments, and it furnishes an efficient directive wireless system which confines the ether disturbances to closely bounded regions and thus offers a ready solution to the serious problems of interferences between messages which of necessity have to be met in wireless operations through space.

The distortion of speech, which is an inherent feature of telephony over wires, should be much less, if not practically absent, when we more and more withdraw the phenomena from the metal of the wire and confine them to a longitudinal strip of the ether which forms the region between the two wires of a metallic circuit.

The ohmic resistance of the wire as shown can be made to play a comparatively unimportant part in the transmission of speech and the more the phenomena are of the ether, instead of metallic conduction, the more perfectly will the modified electric waves, which are the vehicle for transmitting the speech, be delivered at the receiving point without distortion.

It has been shown that the phenomena of resonance, which are met with in so many different branches of physics, exhibit very striking and orderly results when applied to electric waves propagated by means of wires. By utilizing this principle it has been shown that the receiving current at the end of the line may be built up and amplified many times over what it would be with untuned circuits.

The tuned electrical circuit at the receiving end readily admits electromagnetic waves of a certain definite frequency, and bars from entrance electromagnetic waves of other frequencies. This permits the possibility of utilizing a single circuit for multiplex telephony and telegraphy.

DISCUSSION ON "MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES." CHICAGO, JUNE 28, 1911.

Frank B. Jewett: The phenomena which underlie what seem at the present time, to be the most promising lines of investigation for the development of wireless telephony, namely, the utilization of one very high-frequency alternating current as what might be termed the " carrier " for other and lower frequency alternating currents, appeal to the imagination not only of the engineer but also of the physicist. It was consequently with more than usual interest that I commenced an investigation of Major Squier's work in the early part of this year at the time the newspapers first announced the issuance of his patents and described in a general way the character of his discoveries.

My investigation had for its object the determination of whether any of Major Squier's reported discoveries contained the germ of a speech transmission system that could be made commercially applicable in a general, universal telephone system. There were two main questions to be answered, first, were the newspaper accounts of Major Squier's work correct as to what he had accomplished, that is, was it possible even on a single circuit to obtain the results claimed? Second, on the basis of an affirmative answer to the first query was there anything in Major Squier's research that would make his discoveries commercially applicable to either a local or long distance telephone plant? If not, did the research give promise of ultimate commercial adaptation and what further developments would be needed to so adapt it?

I think that Major Squier's paper as presented at this Convention will remove any doubts as to the first of the above queries. Major Squier's paper indicates very clearly that what has been accomplished in wireless telephony, namely, the transmission of intelligible speech by means of a high frequency alternating current carrier, can also be accomplished on a simple telephone circuit consisting of wires, either metallic or grounded, by the same or similar means and apparatus. This being so, we come at once to the second query, namely, that relating to the practical utility of the work in a commercial telephone installation. As yet I have not been able to determine that the research, beautiful though it may be from a physical standpoint, possess any great commercial value or possibilities.

In studying this phase of the matter, it is necessary to take account of all the factors which enter into the design and maintenance of circuits and equipment needed to afford commercial service. In a general telephone plant, the first essential is, a sufficient amount of energy, closely approximating the form in which it was put on the line at the beginning of the circuit, should be transmitted and delivered at the instrument of the receiving subscriber; it is also essential that this be accomplished in such a way and by such means that the plant has a maximum flexibility of operation. Further, from a commercial and operating standpoint it is essential that the circuits used for the transmission of speech be of such a character that the necessary signaling current can be transmitted and that signaling means be provided which will give the operators immediate and complete control of the circuit. While it is not always necessary to transmit the signaling current over the same wires that are used for talking, these currents are usually so transmitted and in any plant for general telephony and telegraphy, where the wires are used to proper efficiency combined talking and signaling currents will in general be found on all wires.

In the matter of the necessary energy to be supplied, a very rapid and cursory examination of the conditions which must be fulfilled in a commercial plant, especially in a long distance telephone plant, will indicate that the general characteristics to be taken account of in considering high-frequency transmission analogous to that suggested by Major Squier are not nearly as simple as on the short circuit which he used between the War Department and the Bureau of Standards in Washington and which, under the circumstances, we might term a laboratory circuit. Further, a few simple computations will show that the attenuation of current at the high frequency which must be used in Major Squier's system is enormously greater than the attenuation at the frequencies which go to make up ordinary speech. The phenomena of current attenuation on long telephone circuits are not different in character for frequencies of from 15,000 to 100,000 periods per sec. than for frequencies of from 200 or 300 to 3,000 periods per sec. and the same attenuation formulas can be used. In rough computation work it is customary for telephone engineers to take a single frequency as designating the average of what takes place in the transmission of speech. The generally accepted single frequency for computation work is 800 periods per sec. Major Squier mentions, as the range of frequencies which are applicable to his adaptation of wireless methods to wire telephony a range from about 15,000 to about 100,000 periods per sec., the lower limit being set by considerations of audibility and by the upper or higher harmonics in ordinary speech and being quite definite. The upper limit is set primarily by considerations of current attenuation and is not quite as definitely marked.

As an illustration of the great difference in attenuation between these high frequency currents and the currents which go to make up ordinary speech transmission, let us consider what will happen on some of the open wire and cable circuits that are ordinarily used in long distance telephony—as examples of these circuits, I have taken first a No. 8 B. W. G. copper circuit, which is the largest copper wire used in commercial telephony in America; second, a No. 12 N. B. S. G. copper circuit, which is the size of wire ordinarily used for rather short toll work and third a No. 13 B. & S. gauge cable circuit, which is about the largest size copper wire circuit generally used in underground telephone cables. Comparing the attenuation of the current at the very high frequencies needed in Major Squier's arrangement to the attenuation at 800 frequency, we find the following:

At 15,000 frequency, which is the lowest frequency Major Squier suggests, the attenuation constant on the No. 8 gauge circuit is 2.2 that at 800 frequency. This ratio increases to 5.4 at 100,000 frequency. On the No. 12 gauge circuit the ratio of high frequency to 800 frequency attenuation constants ranges from 1.6 at 15,000 to 3.5 at 100,000 frequency, while on the No. 13 gauge cable circuit the range is from 1.9 to 4.2 for the corresponding frequencies.

Although the above figures indicate a markedly more rapid attenuation for frequencies above 15,000 than for frequencies in the neighborhood of 1000, they do not show in the most striking manner the serious way in which this rapid attenuation limits the commercial application of any high frequency carrier scheme of telephony. As noted before, it is necessary in a commercial telephone plant to deliver to the subscriber at the distant end of the line a sufficient amount of energy with approximately the form of the current at the sending end to give him an audible amount of sound from his receiver. If we take as a basis of our comparison the amount of energy, which at 800 frequency represents the commercial limit of telephone transmission and assume that at the receiving end of a circuit operated on Major Squier's principle, the amount of energy received in the form of high frequency current is equal in amount to this, and then determine the amount of energy that will have to be put in at the sending end of the line, we obtain some very startling figures.

In obtaining these figures it is assumed that the high frequency receiving apparatus is equal in efficiency to the regular apparatus.

The commercial range for non-loaded No. 8 B. W. G. copper wires is about 1,000 miles and the corresponding lengths for No. 12 N. B. S. G. copper circuits and No. 13 B. & S. gauge cable circuits are respectively 450 and 61 miles. Using these lengths and making the comparison noted above we find that on the 1,000 mile No. 8 B. W. G. circuit it is necessary to put 4,000 times as much energy in at the sending end at 15,000 frequency as is required with 800 frequency, if the energy at the receiving end is to be equal in the two cases. At 50,000 frequency the ratio has risen to 300,000,000, while at 100,000 frequency the ratio of energy at this frequency to that at 800 frequency to obtain the same amount of energy at the receiving end is $7 \cdot (10)^{12}$.

On the 450 mile No. 12 N. B. S. circuit, the ratios for 15,000, 50,000 and 100,000 frequency are respectively 50, $3 \cdot (10)^4$ and $2 \cdot (10)^7$ while for the 61 mile circuit of No. 13 B. & S. cable the corresponding ratios are 500, $1 \cdot (10)^6$ and $3 \cdot (10)^9$.

These figures show, I think, that the problem of applying a high-frequency method of transmission to an existing wire plant would be an exceedingly difficult one, even if there were no other objection to the system and on the assumption that the required terminal apparatus could be readily obtained, due merely to the enormously greater amount of energy required at the sending end of the line. Furthermore, if the system were to be of any great value in a commercial plant, it could not be limited to a single frequency, but would require a large range of frequencies. The figures just given show that with such a range of frequencies the range of energy which must be supplied to lines of similar length will be very great if uniform transmission is to be given. While this might not be a serious objection in a plant comprising but few toll lines, it becomes one of very grave importance when a comprehensive net work has to be taken into account.

I have not as yet been able to see how this difficulty can be overcome in a way that will admit of applying this kind of a system to the complicated requirements of a commercial wire plant. Nor have I yet been able to find affirmative answers to certain other questions which must be satisfactorily disposed of before the device of high-frequency transmission can assume commercial value and proportions.

The more important of these questions are, first, the question of interference between high frequency circuits, 2nd, the question of signaling, and 3rd, the question of modifications required in the existing telephone plant to make possible the application of high-frequency transmission.

With regard to the question of interference, Major Squier points out very clearly that there is no interference between the ordinary talking currents and the high-frequency currents which may be superimposed on the same circuits. This point, can I believe, be granted without further consideration. There would be, however, in a commercial plant operated on the high-frequency system the question of interference between a circuit operated on one of these high frequencies and a neighboring circuit operated with another high frequency. To a certain extent this kind of interference could be avoided by a system of tuning for the terminal apparatus, as Major Squier points out, but we have only to glance again at the figures for the 1,000 mile circuit to see what difficulties there would be in the way of accomplishing commercial results in this manner. Let us consider for example the case of a toll line 1,000 miles long on which there are two pairs of No. 8 B. W. G. copper wires and assume that both circuits are being operated on a high-frequency method and are supplied with sufficient energy at the sending end to give commercial transmission at the distant end. If simultaneous sendings were always from the same end of the line there would probably be no great difficulty in eliminating interference even if there was considerable unbalance between the four wires making up the two circuits. In a commercial plant this simultaneous operation from the same end could not, of course, be obtained, and we have to consider interference between sending on one circuit and receiving at the same end on the neighboring circuit. A consideration of the relatively large amount of energy at the sending end, to give commercial transmission at say 100,000 periods per sec. over a circuit 1,000 miles long shows that a degree of balance between the four wires of the system which is commercially unattainable would be required to block out interference between the sending end of one circuit and the receiving end of the other circuit, even where the two circuits are operated on two rather different frequencies.

Even if it were physically possible to obtain the degree of balance needed for the elimination of interference, that is, to transpose the wires against each other at sufficiently frequent intervals, a scrutiny of the distance factors will show that with open wire lines constructed in the manner ordinarily employed for telephone plants, there are not a sufficient number of poles provided to make possible the necessary transpositions. On well transposed lines for ordinary talking circuits the transposition poles, that is, the points at which the two wires of a circuit are turned over, occur on the average at between one-half and one mile apart, say from twenty to forty poles apart. When we come to consider high-frequency currents of from 15,000 to 100,000 alternations with their very much shorter wave length we find that in order to provide the same number of transpositions per wave length, we would not have a sufficient number of poles in the line as ordinarily constructed and would have to put in additional poles. From this standpoint also, therefore, it will be seen that there are very serious objections to any general application of the idea of using high-frequency current for the purpose of superimposing one talking circuit on another. The same objection arises in the case of cable circuits where current can pass from one circuit to another if there is any capacity unbalance between the pairs of wires which make up the adjacent circuits. Even in the present state of the art the degree of balance required to prevent excessive cross talk is very great and a high-frequency system would necessitate a degree of balance that appears to be commercially unattainable in the present state of cable manufacture.

In order to operate telephone circuits commercially it is necessary to provide means for signaling. The suggestion has been made that in a high frequency system this would not have to be done on the circuits themselves, but that all orders could be passed over special order wires. As noted previously, however, the full utilization of a wire plant in a system devoted to combined telephony and telegraphy practically requires the sending of both talking and signaling currents over the same wires. It would seem, therefore, that this point can not be dismissed so easily and that signaling apparatus must be provided on the talking circuits before a high-frequency system can be considered as having any great commercial applicability. Major Squier points out that in the particular circuit which he used, *i.e.*, a pair of wires in an underground cable, considerable reflection of the high frequency currents occurred at the protecting heat coils in the central offices. If this is so, it is evidence that even the simplest form of relay or retardation coil will act almost as a solid barrier against high-frequency currents unless it is bridged by a condenser.

Thus, even if we could get a sufficient amount of energy over the line it would be difficult to operate a high-frequency relay commercially and at the same time prevent its operation through extraneous disturbance. If, as in the case of the ordinary supervisory relay in a subscribers loop, the apparatus is in series in the line, it would seem to be almost impossible to insure proper signaling operation and at the same time to permit of efficient talking.

The necessity for bridging relays and impedance coils with condensers in order to permit the passage of high-frequency currents would be in itself a very serious bar to any general application of such a system, as it would not only greatly enhance the first cost of the equipment, but would also throw an unduly great burden on the maintenance force. Further, in the case of long distance telephone lines as they exist in this country today and as is pointed out in the paper by Mr. Gherardi on " Commercial Loading of Telephone Circuits," the tendency is to increase the efficiency of the talking circuits by means of inductance coils applied in accordance with Professor Pupin's invention. In this system inductance coils are placed in the circuit at definite intervals, the coils in some cases having an inductance as high as a quarter of a henry each. At the present time the entire toll plant in the long distance system of the American Telephone & Telegraph Co., is rapidly approaching the condition in which all of the circuits contain these inductance or loading coils. There are thousands of these loading coils distributed today along the open wire and cable circuits which form the telephone net work and the problem of applying and maintaining suitable condenser shunts of any form whatever around each individual loading coil would be well nigh insoluble. Also, the presence of these shunts would be seriously detrimental to the efficiency of the circuits for their ordinary use.

I have made one or two short computations to see what this shunting might mean, even assuming that we could maintain condensers around each loading coil, that is that we could build them to withstand commercially the effects of lighting low insulation, etc. For the purpose of comparison let us take the case of a No. 12 N. B. S. aerial copper line which is loaded with inductance coils of 0.25 henry each at eight mile intervals. Further, let us take a frequency of 50,000 periods per sec. which is about midway in the range suggested by Major Squier. In the computation I have assumed that we would install at each loading coil a condenser of sufficient capacity so that the reduced attenuation of the line at 50,000 frequency would not be more than 2½ per cent higher than the attenuation at 50,000 frequency over the same line without any loading coils whatever. This would require a condenser of about 0.04 microfarads for each wire at each loading coil. While such condensers around the loading coils would keep the attenuation at 50,000 frequency down to about 2½ per cent higher than it would be if there were no loading coils on the wire, they would tend to destroy the effect of the loading coils for ordinary talking currents. If we take 1,500 frequency, which is above the mean telephonic frequency but is still within the range necessary for intelligible transmission, we find that the presence of these condensers around each loading coil increases the attenuation by about 7 or 8 per cent. It will thus be seen that for the sake of obtaining a reasonably good circuit for high frequency currents we would have to very seriously impair the talking frequency of our loaded lines when operated in the ordinary way.

In conclusion and as previously remarked I would say that I commenced my investigation of Major Squier's work with a great deal of interest, not only on account of the engineering features involved, but also because the fundamental idea of the system appealed to me very greatly. In the course of this investigation I have had not only the pleasure of reading Major Squier's paper, but in addition the further pleasure of discussing his work with Major Squier personally and of examining his apparatus on the line in Washington and I can assure you that the experiments which he has performed over this line are indeed beautiful. There is absolutely no interference between the battery current and the high-frequency current and over the circuit which he was operating, *i.e*, a relatively short cable circuit, it was easily possible to get a reasonably good volume of transmission with good articulation. As I have already said, however, I have not as yet been able to satisfy myself that there is any affirmative answer to the engineering questions which must be satisfactorily answered before there is any possibility of applying Major Squier's invention generally to a commercial plant used for universal service. I do not say, of course, that it may not be feasible to apply it commercially in certain localized cases where there are special reasons for desiring an additional circuit without the necessity for running additional wires. This could hardly be considered as a general commercial application, for the purpose of extending the range or efficiency of telephonic communication.

E. F. W. Alexanderson: I have prepared for this meeting a paper on "Magnetic Properties of Iron at Frequencies of 200,000 Cycles," but failed to get it ready in time for printing. I just mention this in connection with Major Squier's paper in order to show that 100,000 cycles is not any longer the limit for mechanically generated frequency, but otherwise it is quite clear, particularly in view of the figures shown by Mr. Jewett, that any frequency of 200,000 will be of no value at all for transmission over wires. I have had the same feeling in some experiments I made two years ago—that even 100,000 cycles is altogether too high to be used on a wire service. The experiments were made with the frequency of 10,000 cycles, and the same mechanical parts were used as the 100,000 cycle alternator; however, with a differently designed armature. The pulsating current of the microphone was used as the exciting current of the alternator, which was able to generate a high frequency current of much greater volume than the current used for excitation. The generated current was sent through a mercury rectifier and it was found that an image of the original telephone current could be produced. A special winding was used in order to increase the efficiency, so that the telephone current and the high frequency current flowed in the same conductors.

In connection with those experiments it was naturally thought that there is a possibility of transmitting a high frequency—in that case of 10,000 cycles—over a wire circuit, and in that way have the advantage of tuning the wire circuit to a definite frequency and avoid the distortion of wave shapes, which is bound to occur in ordinary long distance telephony due to the simultaneous transmission of different frequencies. It may be that even 10,000 cycles is too high, in view of the figures that we have had, and it might be out of the question to even use this system for transmission over wires. However, there may be hope for new developments that might solve the problem of long distance transmission. In fact, an alternator is just being constructed by which it is hoped that the frequency of 3,000 cycles can be used without interference with the voice, and in such a case it might seem reasonable that the telephone engineers would find a way of tuning their circuits to approximately 3,000 cycles, and in that way introduce some form of multiplex telephony by which messages may be transmitted long distances without distortion of wave shape or change in the quality of the speech.

John B. Taylor: There are a number of points of similarity between the electric telegraph systems and the electric telephone systems. Therefore, we can profitably look back over the attempts at multiplex telegraphy and see why some have worked out and some have failed.

Various means of separating one set of operators from another set using the same conductor, have been suggested or tried. Some of these means are: (*a*) difference in polarity; (*b*) difference in current strength; (*c*) successive assignment of the circuit to different operators, and (*d*) " resonance " methods. The paper under discussion is an example of the last method. These have all been suggested, and to some extent used on telegraph work. Some of them, I think, we can dismiss right away for the purpose of multiplex telephony.

Polarity seems to be pretty well out of the question, as telephone current is essentially an alternating current and it is hard to see how we can arrange to have one speaker use only currents of one polarity, while other speakers use currents of the opposite polarity.

A method depending on strength of the current seems to be quite out of the question, because the telephone current must go to zero and pass through various values.

The Gray harmonic telegraph system seemed to have great possibilities but, as far as I know, it is nowhere in commercial use. In the paper under discussion we have offered a modification—harmonic telephony in which we are using frequencies so high that the currents do not interfere with standard telephone apparatus, and it is intimated that a number of frequencies may be used for independent telephonic conversations. The complications would seem to be much more in the case of the telephone than with the harmonic telegraph, and the latter has not yet proved successful.

The other possibility, the successive assignment of the line to one station and then to another, (in the " synchronous telegraph " use is made of a so-called " sunflower " rotating distributor whereby the line is assigned for a short space of time, first to one operator and then to another) may be considered for telephony. It is surprising how much can be eliminated from the telephone current and still have recognizable speech. There are various ways of attacking the problem of multiplex telephony, and some have possibilities.

The system of multiplex telephony under discussion is a resonance method making use of intensity variations in the strength of an alternating current of frequency greater than that to which the standard telephone receiver and human ear are sensitive.

Major Squier refers to the possibility of solving the problem by the use of a similar method in which the transmitted alternating currents are of frequency below those to which the ear is sensitive, or in the neighborhood of 16 cycles per sec., but has apparently dismissed this from serious consideration on account of the difficulty of securing a pure sine wave.. It may be well to point out here that entirely apart from any question of difficulty in securing a perfect sine wave of the frequency of 16 cycles or lower, that such a system is fundamentally wrong for purposes of speech transmission. That this is the case will be evident on slight consideration. Fairly rapid speech may have as many as ten distinct syllables in each second, so that one or more of these syllables occurring at or near the zero part of the 16 cycle wave, would be either entirely lost, or of such low intensity compared with those syllables occurring at or near the peaks of the 16 cycle wave, as to seriously change the quality of the speech. This is not equivalent to saying that speech over such a low frequency system could not be recognized, but that the distortions are so great as to debar the matter from serious practical consideration. In some of my own tests, making use of alternating currents of relatively low frequency as a source of current supply in the transmitter circuit, instead of the usual cells of battery, and working with simple musical tones instead of the more complex speech, some very curious effects were noted, which can not be discussed at this time beyond mentioning the fact that the simple musical tone of the source comes out of telephone receiver as a compound tone (generally a discord) apparently consisting of two tones, one of pitch corresponding to the sum and the other to the difference of the frequency of the musical tone and the frequency of the alternating current source of energy.

Dr. Jewett has satisfactorily answered many of the questions that naturally come to mind on first acquaintance with the general scheme of Major Squier's system, and the figures Dr. Jewett has given showing the enormous sending current required for a moderate receiving current over a line of sufficient length to justify the employment of high frequency generators and other special apparatus, tell at least one of the difficulties in the way of putting such a system into commercial operation.

S. G. McMeen: Dr. Jewett's statement, as to the lack of the ability to signal over the strip of ether, impels me to remark that we have good, useful physical circuits today over which we can not signal in the ordinary sense. I refer to composited lines, from which the usual signaling ability is taken away by adding the telegraph. But we do use such circuits to great advantage, and without trying to signal over them.

Dr. Jewett comments on the hurtfulness of series windings, such as relays, in these high-frequency circuits. Series windings, other than loading coils, have steadily become less common in all telephone circuits during the last 20 years. All reactances required in Major Squier's methods, whether of capacity or inductance, are of small dimensions because of the high frequencies. It easily may come about that the capacities may be sufficient when formed of a few turns of wire laid side by side.

Mr. Alexanderson says there is hope for further development. It is that outlook which makes this work notable. Since 1900, there has been no announcement of large addition to our fundamentals in telephony. We may well consider this work another such addition.

Mr. Taylor says the harmonic telegraph did not make good. It *did* give us one great result: Observation of a single phenomenon in harmonic telegraph experimentation diverted Professor Bell directly to the invention of the telephone.

Dr. Jewett further says that Major Squier's invention is "a beautiful laboratory apparatus." I beg to remind him that the telephone itself was that, *and that only*, when Professor Bell finished it.

Frank F. Fowle: Major Squier's achievement in duplexing a telephone circuit by superimposing waves of a frequency beyond the range of audibility will rank high among scientific accomplishments. It marks a new and extremely interesting development in the art of telephony.

Telephone engineers will analyze it in the light of their experiences with voice transmission, at relatively low frequencies, ranging from 100 to 2,000 cycles per second. As others will doubtless point out, it appears to have serious defects and a very limited commercial value from such a standpoint. There are two fundamental reasons for this. In the first place, the rate of attenuation at such high frequencies will be relatively enormous in comparison with the values of attenuation now obtained with voice frequencies. Consequently the maximum attainable distances will fall far short of present accomplishments, even at comparatively high impressed voltages. Secondly, and perhaps of most import, the difficulties of preventing cross-talk between two or more high-frequency circuits in the same cable or on the same pole line appear to constitute an almost insurmountable problem.

For these reasons Major Squier's invention seems to have a very limited commercial value at present, at least in relation to its use on existing wire plants. As to its ultimate value it is unsafe to predict, because it opens the door of a new development whose possibilities are yet unexplored.

The two large problems needing immediate attention are those of minimizing the attenuation and controlling the cross-talk. It seems fairly apparent that the lowest safe frequency from the standpoint of interference will be the best one, because thus the attenuation is made a minimum. The control of cross-talk is perhaps the most difficult problem. In this connection it may well be pointed out that for high-frequency transmission the present situation is parallel to the one which existed 30 years ago in the development of long distance transmission at synchronous frequencies. The grounded line of those days gave serious trouble from cross-talk as soon as appreciable parallel lengths were exposed to each other. The metallic return diminished the difficulties but was not a satisfactory remedy. It was not until the transposed metallic circuit was developed, through the work of Carty and Barrett, that long-distance service became commercially feasible in 1885.

Apparently the wire plant of today will need radical alterations to permit secret transmission over high-frequency circuits lying side by side for many miles. If this can be accomplished without sacrificing present efficiency in relation to the use of the composite and the phantom, it will bring Major Squier's achievement to a state of great social and industrial value.

In connection with the paper I note that the measured constants of the cable circuit employed are very unusual. The measured loop resistance averages 110 ohms per mile, which is normal with the gauges used. But the capacity of 0.69 microfarad, if it represents the whole seven miles, is much too low;

it might be very nearly right if it represented the mutual capacity per mile. The insulation resistance is exceedingly low and indicates very poor conditions somewhere in the circuit.

Béla Gáti: I have made a number of experiments from which I conclude that Major Squier's explanations are not always right.

It seems Major Squier has not enough measuring instruments for alternating (high frequency) currents. Major Squier measures the capacity (one minute electrification) and the insulation resistance with direct currents. He does not say so but the " one minute electrification " verifies my opinion. I have written a number of articles discouraging the use of direct-current measurements for high-frequency circuits. There is no connection between direct-current isolation and high-frequency dielectric resistance. I found the latter one is 1,000 to 10,000 times smaller than the direct-current value. I believe the isolation (dielectric resistance) of the said telephone cable can be only some hundred ohms. I should like to have data obtained by measurement with 20,000 to 100,000 cycles.

Major Squier states that: " The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles . . . " This opinion is the most dangerous one imaginable, for the future. We know that in wireless telegraphy the damping factor depends, in the first place, on the energy consuming resistances. How Major Squier's opinion was formed, can only be explained as follows (*a*) by the phenomenon that when the current is over a certain value, (5 milliamperes on the Hungarian receivers) the telephone receiver does not give a stronger sound. I showed these curves relating to this phenomenon at the second conference of the Telephone Techniciens in Paris. If we have 4, 8 or 12 milliamperes received currents in the receiver, the sounds remain about of the same strength and so we cannot judge, by hearing, the strength of the incoming currents, nor the total resistance of the line.

(*b*) As I have already stated, the insulation for high frequency current must be very small, the capacity between the wires is large enough, the cross-talk for these cycles exists and so we cannot speak about the ohmic resistance of one wire, but only of the whole cable bunch. Major Squier found the transmitting impedance under 100 ohms (87) for high-frequency-currents, and one metallic circuit had 776 ohms resistance.

(*c*) I experimented with telephoning on single aerial wires. I had the same effect at the receiving station (2,500 km., 4 mm. diameter bronze wires), whether the two wires were connected in parallel or not. Then I changed the line, using a three-mm. wire, and have spoken over only 1,000 km. instead of 2,500 km. In this case the whole line, if the cross-talk is not avoided, forms only one wire.

I hope that Major Squier will make other experiments and verify my explanation. Assume for example, that the Commercial Cable Co. should have a new cable laid between New York and England with a self inductivity 10^{-2} henry per kilometer, but 10 ohm resistance instead of 0.9 ohm, provided Major Squier's opinion about the ohmic resistance is a correct one. This new cable with 10 ohms per kilometer would be a complete failure, but with 0.9-1 ohm resistance and with the same 10^{-2} henry inductivity this could alone make up for all the other Atlantic cables and make the cable rates 10 times cheaper.

The present type of microphones are not fit for high-frequency currents. The microphone effect is caused by the imperfect contacts; for high-frequency currents there are no imperfect contacts; they make conductive the worst contacts of the crystal detectors, therefore the need is felt for another type of microphone. I made experiments with 4,000 cycles, and was able to throw out the disturbing effect of the ground-current. Today, I believe the frequency of about 10,000 cycles is the best. The telephone receiver does not respond to disturbances when the cycles are over 7,000.

TABLE I

THE SPEED OF ELECTRICITY ON BRONZE WIRE TELEPHONE CIRCUITS

$\omega = 2\pi n = 9000$	$v = 240{,}000$ km.
8000	239,500
7000	239,000
6000	238,000
5000	237,500
4000	235,500
3000	231,500
2000	222,000
1000	196,000
628	173,000
263	133,500
131	112,500
62	101,000
31	97,000
18	95,500

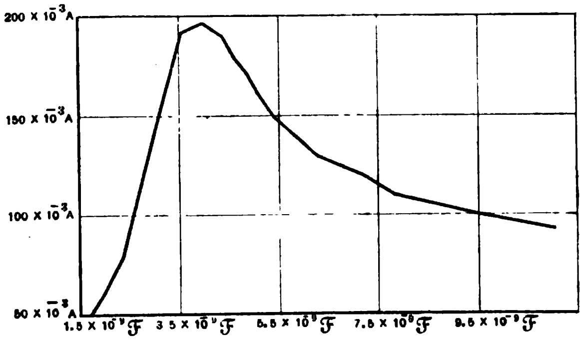
Telegraphy with high frequency currents is an old thing; I experimented with it many years ago and worked it out especially for cable telegraphy. I am glad that Major Squier's experiments confirmed the unlimited possibilities of this kind of telegraphy; perhaps existing cable-companies will now pay more attention to it.

Major Squier uses the $\lambda = 2\pi V \sqrt{L C}$ expression and supposes that $V = 300{,}000$ km. per second. According to my experiments on aerial lines (Table I) it can be said that the speed is *never* 300,000 km. I made various experiments and have never found this value. I do not believe that this 300,000 km. is a definite value. According to Kennelly's formula $V = \frac{w}{\beta_2}$ where

$$\beta_1 + j\,\beta_2 = \sqrt{(r + j\,\omega\,l)\,(g + j\,w\,c)}$$

I will not say that in the case of the cable line $V = 500{,}000$ km., as the preliminary computation shows this, but I am of the opinion that V differs from the value of 300,000 and so the resonance curves and other computations of Major Squier are incorrect.

The same is applicable to the L^1 0.260 millihenry value. The cable line has a comparatively large capacity joined in series with the tuning capacity; this also somewhat modifies the result.



Resonance curve

I believe for effective voltage measurements the string electrometers, for instance Woulff's electrometer with short platinum string, are sensitive enough even for small values. The impressed voltage is surely larger than one volt, and thus measurable.

In my experiments the resonance curves were also unsymmetrical. I constructed curves at one single frequency; the ordinates were the currents in milliamperes, the abscissas were the capacity values in microfarads. I found the cause of the unsymmetrical position in the dielectric resistance of the condensator. According to my experiments 0.001 microfarad has at $w = 2\,\pi\,n = 10{,}000$ a dielectric resistance, (isolation) about 1 megohm, but 1 microfarad capacity has about 1,000 times less, that is only 1,000 ohms. This dielectric resistance is not constant, it is for higher frequencies less so; I believe this diminution of the isolation (dielectric resistance) for higher frequencies causes the unsymmetrical state. I obtained the values of the resonance curve, ($n=95{,}200$) according to my process, the ordinates were the milliamperes, the abscissas, the capacities. This curve was very unsymmetrical.

I constructed the curves not only for the outgoing but also for the incoming currents. In wireless telegraphy from these resonance curves the attenuation is computable. Of course, the hypothesis is that the curve of the resonance is symmetrical; perhaps some one could find the mathematical expression of the attenuation from these unsymmetrical curves. It would be very useful for long distance telegraphy to have them. The measuring of the ratio of the outgoing and incoming current is only applicable over some thousand kilometers distance; at this distance, the disturbing (vagabond) currents are always larger than the talking currents, and so the measurement is very difficult.

The selectivity curve is in reality the same as the resonance curve; hence the unsymmetrical position.

Of course, it would be more interesting to know the selectivity curves of the received (incoming) currents. My barretter set measures without shunt to one milliampere, with shunted galvanometer, to 5-10 milliamperes maximum values (pointer-galvanometer), beginning the measurement with 0.5-0.1 milliampere, which is the value of the commercial talking (received) telephone-current. If Major Squier wants to make experiments over some 100 or 1,000 kilometers, he will need this instrument, therefore I call his attention to it.

The manufacture of large condensers with large dielectric resistance is the most difficult problem in high frequency telegraphy. Perhaps it would be of interest to know that I use the condensers of Mr. Szvetics, (the director of the Telephone News, in Budapest) which I have found the best and the most practical for this purpose.

On cables, the voltage has no tendency to rise after having thrown in resonance, but on aerial lines I experienced the increase of the received currents. At open ends there is always increase in voltage. Probably Major Squier will make further experiments with 100,000 cycles; I should like to know the results.

The small dielectric resistance (isolation) of the cable causes the phenomenon that the resonance curve is the same when the distant end is open or short circuited. I experienced on aerial-lines that the outgoing current was always larger when the distant end was *opened*. At the short circuited distant end the outgoing current is only a small value of the former. This seems at the first moment very strange; Kennelly's formulas (hyperbolical treatment of telephone-currents), however, explain it quite correctly.

When the impedance of the whole line is 87 ohms, it is not permissible to measure with a galvanometer which has 171 ohms. The so called attenuation curve in Fig. 22 Major Squire's paper is the attenuation curve of this galvanometer (at least 60 per cent) and not of the line. When the outgoing current decreases from 240 milliamperes to 5-1 milliamperes at 11.26 kilometer distance, it proves the system to be a disadvantageous one. With barretter set (1-10 ohm resistance) Major Squier could obtain more current at the receiving end. We see here that the effective ohmic resistance is a very important one for these high-frequency currents. Of course the outgoing current must be in resonance.

I have the same opinion regarding the submarine cables as Major Squier. A cable with 10^{-2} self inductivity per kilometer and working with high-frequency current would be able to settle the whole business of the existing Atlantic cables. The rates could be decreased to two cents per word. This time is not so far off; however, at the present time, the cable companies are too conservative. On account of this, I emphasize again that the ohmic resistance of the wire is a very important one, and one unsuccessful experiment could cost millions of dollars and prevent the application of the high-frequency currents for some decades.

Finally, allow me to congratulate Major Squier. My above remarks are not intended as a criticism. I had no intentions of that kind. I simply wanted to communicate the results of my experiments made during the past eight years and thereby hasten the development of high frequency telegraphy and telephony. I will further remark that with high-frequency currents the speed is unlimited. I succeeded in sending 20 to 60 letters per second. The signals are not intermixed, the incoming signal is not expanded as in direct-current telegraphy. The German Telephone Experiment Station in Berlin (Mr. K. W. Wagner) claims and also deduces mathematically that the signals are expanded at high-frequency currents. But this statement is quite incorrect. I have made experiments over a 4000-km. line; the direct-current signals were expanded perhaps 300 per cent, the alternating current signals not at all.

Telephoning with high-frequency currents has also been attacked, but I proved mathematically (Electrotechnische Zeitschrift, 1909, copy 39) the possibility of talking between London and Kurachi (India) a distance of 8000 km.

This statement as well as a lot of statements like the expansion are ones which we are obliged to disprove with experiments. I should be very glad if Major Squier as well as others would continue experiments along these lines so as to help us in this matter.

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

TELEGRAPH TRANSMISSION

BY FRANK F. FOWLE

I. INTRODUCTORY

The theory of telegraph transmission, in its broadest aspect, involves the many systems which have appeared from time to time. A treatment of them all is much beyond the scope of a paper of this nature, but fortunately a great many can be eliminated by reason of their limited commercial use. The considerations in this paper are limited to the closed-circuit Morse system, which has been practically supreme in American practice for many years. High-speed automatic systems have enjoyed but little use in this country and a theoretical consideration of such transmission, while very interesting, has a limited practical value at the present time. Considering its commercial importance, it is not easy to understand why the theory of Morse transmission has remained so long in a state of apparent neglect. Perhaps this is due in some measure to the difficulty of the subject, but certainly it cannot be ascribed to the lack of interesting or commercially important problems.

The full solution of transmission problems of any character involves the well known differential equation which expresses the relation between the line potential, the distance, the time and the line constants, as given below.

$$\frac{d^2 E}{d s^2} = L\, C \frac{d^2 E}{d t^2} + (C\, r + L\, g) \frac{d E}{d t} + r\, g\, E \qquad (1)$$

in which E = line potential.
s = distance from the source.
t = time.

r = line resistance.
g = leakage conductance.
C = line capacity.
L = line inductance.

The general solution of this equation, involving terminal conditions, is complicated and not readily handled; the most general case involves oscillatory charging and discharging of the line during the transient state. An abridged treatment of less general difficulty is very desirable for the solution of the more important commercial problems.

When the line is very highly insulated and possesses substantially no inductance, as in cable circuits, the full theory is considerably simplified. In that case the well known $K R$ law has been employed empirically by many engineers. The same law has also been applied to the case of open-wire lines, where theoretically it fails to hold because such lines possess considerable leakage and some inductance. Mr. T. E. Herbert* has developed the following empirical formulæ, based on the $K R$ law, from English practice.

$$W_1 = \frac{10{,}000{,}000}{K R} \tag{2}$$

for open-wire lines of iron,

$$W_2 = \frac{12{,}000{,}000}{K R} \tag{3}$$

for open-wire lines of copper, and

$$W_3 = \frac{18{,}000{,}000}{K R} \tag{4}$$

for cables of the submarine type with gutta-percha insulation; W is the speed in words per minute, K is the total capacity and R is the total resistance. The assumed conditions are eight milliamperes of line current and not less than 100 volts of impressed e.m.f., from a source whose internal resistance does not exceed three ohms per volt; he also assumes a shunted condenser

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*"Telegraphy," by T. E. Herbert. Whittaker & Co., London, 1906. Chapter XVII.

at the receiving end. For a speed of 400 words per minute he gives the following limits of distance.

	Miles	Km.
150-lb. aerial copper line	590	949.5
100-lb. " " "	487	783.7
450-lb. " iron "	363	584.1
400-lb. " " "	291	468.3
G. P. underground	83	133.5
Screened paper cable, 40-lb	128	205.9

No qualification with respect to line insulation is there given, but that factor is most important, at least in American practice. Empirical rules must be used with the greatest care to see that the imposed conditions are fully satisfied in any specific application. Such rules also possess the disadvantage that they fail to reveal the theoretical relations between the numerous variables and hence do not show, except in a limited way, how to improve transmission or economically proportion the terminal equipment with respect to the line circuit.

In the type of Morse transmission which we are considering there are two fundamental requirements. First, the strength of signals must be adequate to cause firm registration in the terminal apparatus and, second, the speed of transmission must exceed the rate of hand sending by a safe margin, without diffusion or obliteration of the line impulses. Theory and experience both demonstrate that the limit of distance over circuits of the pure cable type is fixed by considerations of speed, due to the retardation and the absorption caused by the relatively large capacity of the line. That is, signals of adequate strength can be transmitted over very great distances with circuits of such a type, but not at a speed commensurate with an operator's maximum capacity for hand sending.

Open-wire lines, on the other hand, possess much less capacity per unit of length and under conditions of high insulation give a satisfactory speed, for rapid hand sending, over distances ordinarily several times the limit with the usual type of cable. But the insulation is far from constant and fluctuates between wide limits with atmospheric changes. During clear dry weather it will be quite high if the line is maintained in first-class condition, perhaps as high as 50 megohms per mile. During heavy prolonged rainfall it may not be greater than a small fraction of a megohm. Such low insulation ordinarily fixes the limiting distance of transmission, through impairment of the strength of the signals; and this limit, in nearly all cases, is considerably below the limit fixed by considerations of speed.

Experience with long lines of open wire shows very clearly that the workable limit, through all weather, is fixed primarily by the leakage, with attendant weakening of signals, rather than by considerations of speed. In determining the proper line constants for transmission between two given points, it is proper to assume that continuous service is desired; in fact a service which depends upon the vagaries of weather is utterly untrustworthy and impossible commercially.

If we can investigate the problem from the single standpoint of the strength of signals, the theory is much simplified. The author believes from his experience with long lines comprised mainly of open wire, that this is feasible and safe. A complete investigation of Morse transmission, under this assumption, gives results which are well in accord with experience and leads to the conviction that the method, within proper limits, is a satisfactory one. This point will be discussed further in connection with the actual results of such an analysis and their application.

When the theoretical treatment is limited to an investigation of the strength of signals, the time element disappears and the differential equation given by expression (**1**) becomes simply

$$\frac{d^2 E}{d s^2} = r\, g\, E \qquad (5)$$

the solution of which is not difficult.

II. General Theory

The general solution of (**5**) is

$$E_s = A\ \epsilon^{-\beta s} + B\ \epsilon^{-\beta s} \qquad (6)$$

where A and B are constants which are fixed by the terminal conditions.

The constant β is the familiar attenuation constant and

$$\beta = \sqrt{r\, g} \qquad (7)$$

where r = line resistance in ohms per mile.
g = leakage conductance in mhos per mile.

If R is the insulation resistance of one mile of line expressed in ohms,

$$g=\frac{1}{R} \tag{8}$$

The general expression for current is

$$I=-\frac{1}{r}\frac{dE}{ds} \tag{9}$$

which follows from the fact that the underlying equations are

$$\left.\begin{aligned} -\frac{dE}{ds}&=rI \\ -\frac{dI}{ds}&=gE \end{aligned}\right\} \tag{10}$$

and these expressions give (5) by elimination.
Hence

$$I_s=\frac{-A\,\epsilon^{\beta s}+B\,\epsilon^{-\beta s}}{K} \tag{11}$$

where

$$K=\sqrt{\frac{r}{g}}=\sqrt{rR} \tag{12}$$

and K is the apparent resistance of an indefinitely long line, measured from $s=0$. When the line is indefinitely long,

$$E_s=E_0\,\epsilon^{-\beta s} \tag{13}$$

and

$$I_s=\frac{E_0}{K}\,\epsilon^{-\beta s} \tag{14}$$

where $\epsilon^{-\beta s}$ is the attenuation factor.

But this is not the condition encountered in practice, although of interest theoretically. Terminals are present, with resistances and sources of e.m.f. arranged in a number of ways. The general solution can be carried no farther without knowledge or assumption of the specific terminal conditions, and it is necessary to treat each arrangement separately. The simplex, duplex and quadruplex systems will be considered in order.

Simplex. The standard American simplex or method of single working, on the closed-circuit plan, is illustrated in Fig. 1.

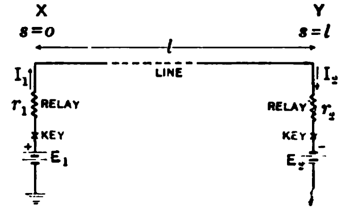

FIG. 1.—Circuit of standard simplex.

This circuit is too well understood to need explanation. There are three conditions to be investigated mathematically. First, both keys closed; second, key open at X or $s=0$; third, key open at Y or $s=l$, while the opposite key, as before, is closed.

In the first case, with both keys closed, the condition at $s=0$ is

$$A+B=E_1-r_1\,I_1 \tag{15}$$

and at $s=l$ the condition is

$$A\,\epsilon^{\beta l}+B\,\epsilon^{-\beta l}=-E_2+r_2\,I_2 \tag{16}$$

which follow from the fact that the batteries are connected in conjunction to send a current in the positive direction over the line, from X to Y; and, similarly,

$$I_1=\frac{-A+B}{K} \tag{17}$$

$$I_2=\frac{-A\,\epsilon^{\beta l}+B\,\epsilon^{-\beta l}}{K} \tag{18}$$

By elimination among the last four equations it follows that

$$A=\frac{-\alpha_2\left(\frac{1+\alpha_1}{2}\right)\epsilon^{-2\beta l}.E_1-\left(\frac{1+\alpha_2}{2}\right)\epsilon^{-\beta l}.E_2}{1-\alpha_1\,\alpha_2\,\epsilon^{-2\beta l}} \tag{19}$$

$$B=\frac{\left(\frac{1+\alpha_1}{2}\right)E_1+\alpha_1\left(\frac{1+\alpha_2}{2}\right)\epsilon^{-\beta l}.E_2}{1-\alpha_1\,\alpha_2\,\epsilon^{-2\beta l}} \tag{20}$$

where

$$\alpha_1 = \frac{K - r_1}{K + r_1} \tag{21}$$

$$\alpha_2 = \frac{K - r_2}{K + r_2} \tag{22}$$

and α_1 and α_2 are termed reflection coefficients by analogy with similar coefficients in the case of alternating-current or wave transmission.

The solution in any given case may now be calculated in full for the first condition, remembering that

$$\epsilon^{\pm \beta x} = \log_{10}^{-1}(\pm 0.43429\, \beta\, x) \tag{23}$$

or

$$\epsilon^{\pm \beta x} = \cosh \beta\, x \pm \sinh \beta\, x \tag{23a}$$

In the second case, when the key is open at X and closed at Y, the proper values of A and B can be found from (19) and (20) by assuming that

$$r_1 = \infty \tag{24}$$

and

$$\alpha_1 = -1 \tag{25}$$

which give,

$$A = B = \frac{-\left(\frac{1+\alpha_2}{2}\right) \epsilon^{-\beta l} . E_2}{1 + \alpha_2\, \epsilon^{-2\beta l}} \tag{26}$$

And similarly, when the key is open at Y and closed at X,

$$r_2 = \infty \tag{27}$$

$$\alpha_2 = -1 \tag{28}$$

and

$$A = \frac{\left(\frac{1+\alpha_1}{2}\right) \epsilon^{-2\beta l} . \mathrm{E}_1}{1 + \alpha_1\, \epsilon^{-2\beta l}} \tag{29}$$

$$B = \frac{\left(\frac{1+\alpha_1}{2}\right) E_1}{1 + \alpha_1\, \epsilon^{-2\beta l}} \tag{30}$$

It is almost self-evident that signals will not be transmitted in each direction over a uniform line, with equal efficiency and like effects, unless the terminals are alike as to resistance and magnitude of e.m.f. The similarity of terminals is essential to uniformly efficient service; this condition will be assumed for the present and the results of the alternate condition will be taken up later.

Therefore, assuming that

$$\left.\begin{aligned} E_1 &= E_2 = E_0 \\ r_1 &= r_2 = r_0 \\ \alpha_1 &= \alpha_2 = \alpha \end{aligned}\right\} \tag{31}$$

it follows that

$$\alpha = \frac{K - r_0}{K + r_0} \tag{32}$$

and (19) and (20) become

$$A = \frac{-\left(\frac{1+\alpha}{2}\right) \epsilon^{-\beta l} . E_0}{1 - \alpha\, \epsilon^{-\beta l}} \tag{33}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right) E_0}{1 - \alpha\, \epsilon^{-\beta l}} \tag{34}$$

(26) becomes

$$A = B = \frac{-\left(\frac{1+\alpha}{2}\right) \epsilon^{-\beta l} . E_0}{1 + \alpha\, \epsilon^{-2\beta l}} \tag{35}$$

(29) and (30) become

$$A = \frac{\left(\frac{1+\alpha}{2}\right) \epsilon^{-2\beta l} . E_0}{1 + \alpha\, \epsilon^{-\beta l}} \tag{36}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right) E_0}{1 + \alpha\, \epsilon^{-\beta l}} \tag{37}$$

The effect of opening the key at X, upon the current in the relay at Y, will depend upon the length, resistance and leakage conductance of the line. If the line is perfectly insulated, the current at Y will be interrupted entirely; but when there is some degree of leakage, the current at Y can never be interrupted wholly, but will be diminished somewhat. This is caused by the fact that the battery at Y finds a completed circuit through the leakage path to earth, that is, current escapes over the wet insulators and thus returns to the terminal through the earth. The adjustments of a standard telegraph relay can be varied to suit a large range of operating conditions. On a perfectly insulated line the operation of the relay is exceedingly positive, because the line current ceases entirely when a key anywhere is opened. But on leaky lines the situation is different and the opening of a key merely diminishes the current, without ever interrupting it wholly. In the last case the relay must be adjusted, say, to pull up on 50 milliamperes and release when the current suddenly falls to 30 milliamperes. Clearly the releasing current will become larger as the leakage effect increases and an ultimate limit of operation will be reached.

The essential phase of the problem which needs our next attention is the ratio of the releasing current to the operating current at Y when the key at X is opened and closed, or the reverse, but since the terminals are alike it makes no difference which case we consider—the results will be identical. When both keys are closed the current at the Y terminal is

$$I_2 = \frac{\left(\frac{1+\alpha}{2}\right)(1+\epsilon^{-\beta l})\,E_0}{K\,(1-\alpha\,\epsilon^{-\beta l})} \tag{38}$$

And when the key at X is open the current at Y is

$$I_2' = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-2\beta l})\,E_0}{K\,(1+\alpha\,\epsilon^{-2\beta l})} \tag{39}$$

The ratio of the currents is

$$\phi = \frac{I_2'}{I_2} = 1 - \frac{1+\alpha}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}} \tag{40}$$

which can be put in the form

$$l=\frac{2.303}{\beta}\log_{10}\left[\frac{n\,(1+\alpha)+\sqrt{n^2\,(1+\alpha)^2-4\,\alpha}}{2}\right] \tag{41}$$

where

$$n=\frac{1}{1-\phi} \tag{42}$$

The last two expressions give the maximum permissible length of line in terms of the wire resistance per mile, the leakage conductance per mile, the reflection coefficient and the greatest permissible ratio of releasing to operating current for commercial operation of the relays. The problem is then solved, for uniform lines with equal terminals.

The next question is whether anything can be gained by an unsymmetrical arrangement of the terminals. In the most extreme case all the battery would be at one terminal, say at Y. This condition amounts to placing $E_1=0$. When transmitting from Y to X the value of ϕ would be zero, aside from the effect of earth potentials, because the current at X would cease entirely upon opening the key at Y. But this would not be the case in transmitting from X to Y. By placing $E_1=0$ in (**19**) and (**20**) and employing the resultant values of A and B to find the value of ϕ for the present case, which will be designated ϕ', it can be shown that

$$\phi'=\phi\,(2-\phi) \tag{43}$$

Therefore ϕ' is larger than ϕ for all values of the latter between zero and unity—which is the range of ϕ. But an increasing value of ϕ or ϕ' corresponds to a diminishing margin of operation in the relays and if ϕ is at the practicable limit, ϕ' will be beyond it. That is to say, a line of given resistance and leakage can be operated the maximum distance when the battery is distributed one-half at each terminal.

The terminal resistances also affect the final result because they enter into the expression for the reflection coefficient, which in turn is one of the factors in (**41**). Unequal resistances obviously upset the symmetrical condition and do not give as great a value of l as would be obtained with the same total resistance distributed in two equal terminals. The effect of α on the value of l will be discussed later.

One more question remains to be settled. It is not obvious that working from terminal to terminal is the most difficult case which arises. Any doubt in the matter can be quickly settled, however, by considering transmission to and from the center of the line. When all keys are closed the current at the center can be found by making $s=\frac{l}{2}$ in **(11)** and employing **(33)** and **(34)** for A and B. When either terminal key is open, the current at the center can be found as in the similar case of the whole line, by placing the proper reflection coefficient equal to minus unity and again making $s=\frac{l}{2}$. In the case of an open key at the center of the line the terminal current is readily found from the previous solution by substituting $\frac{l}{2}$ for l.

For transmission from either terminal to the center of the line, the ratio of currents at the latter point is

$$\phi''=\tfrac{1}{2}\,\phi \qquad \textbf{(44)}$$

which means that the fractional margin of current for relay operation is twice as large at the centre of the line as at the terminals. This proportionality between distance and margin does not hold for other points on the line, however.

Assuming that there is a key at the center of the line, the ratio of terminal currents when this key is open and closed is given by

$$\phi'''=\frac{\phi}{2-\phi} \qquad \textbf{(45)}$$

which means that for values of ϕ between zero and unity, the corresponding values of ϕ''' are always less, and hence the margin is greater.

By taking other intermediate points it can be shown that the most difficult transmission is always from terminal to terminal. This conclusion agrees entirely with experience; in the case of long and heavily loaded way circuits it has sometimes been found impossible to work through from end to end in the most severe weather, but at the same time an office near the center of the line can work with either terminal and repeat through messages.

Differential Polar Duplex.—The circuit of the differential polar duplex, operating with current reversals, is shown in theory in Fig. 2.

This circuit can be readily understood by considering its action in the case of a perfectly insulated line. The line current flows through one-half of each polar relay and the artificial line currents flow through the other halves. But under normal conditions the terminal batteries are in opposition as shown in the illustration and the result is no line current. A battery reversal at either end places the batteries in conjunction and the line current then has full strength. The polar relays are always so connected as to be differential to outgoing currents, and a neutral balance is found by disconnecting the distant battery and grounding, and then adjusting the artificial line at the home end. The operation is then repeated for the opposite terminal, but this may upset the first balance slightly and if so, the whole operation must be repeated. In the absence of earth potentials the relays need no bias, but otherwise some bias is necessary.

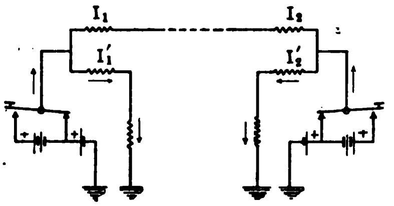

FIG. 2.—Circuit of differential polar duplex.

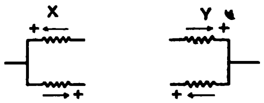

FIG. 3.—Normal direction of currents in polar relay for no response.

Under normal conditions, with no line current, the relays are held open by the currents in the respective artificial lines, and the current in each case is furnished by the home battery. When the battery at X, for example, is reversed, the home relay is not affected but the distant relay responds. There are four key combinations to consider and in order to study them all the operating currents will be taken as shown by Fig. 3.

The positive directions of current shown in Fig. 3 are assumed to hold the relays open, while negative effects will close them. It may next be observed that the line current, when the batteries are in conjunction, will be approximately twice the value of current in either artificial line under normal conditions. The relative effects with the four key combinations are given in Table I.

Referring to Table I, a net current effect of +1 corresponds to a normal or open relay, while a net effect of −1 corresponds to a closed or actuated relay and a transmitted signal. This elementary explanation serves very well to obtain a grasp of the operation in general, but when line leakage is introduced the effects are more complicated. In the last case the line currents, with one exception, are never zero; when the batteries are in opposition a current of some magnitude issues from each terminal and flows to earth over the leaky insulators, but the current at the exact center of the line is zero. The effect of this current is to reduce the net magnetizing force which holds the relay armature against the back-stop. When the batteries are in conjunction the line current increases materially; but the magnitude of the change in line current, when the batteries change from opposition to conjunction, becomes less and less as the line leakage increases and the net magnetizing force which controls the relay becomes correspondingly less. Thus a limit of operation will be reached with a line of fixed characteristics; that is, there will be a limit of workable or operative distance.

TABLE I

ELEMENTARY OPERATION OF DIFFERENTIAL POLARDUPLEX

Key		Relay at *X*			Relay at *Y*		
at *X*	at *Y*	I_1	I_1'	I_1+I_1'	I_2	I_2'	I_2+I_2'
open	open	0	+1	+1	0	+1	+1
"	closed	−2	+1	−1	+2	−1	+1
closed	"	0	−1	−1	0	−1	−1
"	open	+2	−1	+1	−2	+1	−1

Before investigating the circuit mathematically, it may be well to point out a secondary effect on relay operation, here present. The source of e.m.f. will ordinarily have some internal resistance or else be protected by a resistance in the battery or generator tap. Consequently the current in the artificial line will vary slightly with changes in the main line current, due to changes in applied e.m.f. This effect should be taken into account because it changes the margin of relay operation.

The previous discussion of terminal conditions with respect to equality applies also in this case, and like terminals will be assumed. The new terminal conditions make the previous analysis inapplicable. The circuit as it will be treated analytically is given in Fig. 4.

The resistance r_2 is the internal battery resistance or the protective resistance when storage batteries or generators are employed. The resistance r_1 is the line portion of the polar relay and r_3 is the other half of the polar relay plus the artificial line.

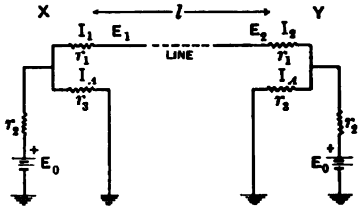

FIG. 4.—Differential polar duplex in theory.

The apparent resistance of the complete terminal is obviously

$$r_0 = r_1 + \frac{r_2\, r_3}{r_2 + r_3} \tag{46}$$

and the effective terminal e.m.f. is

$$E_0' = \left(\frac{r_3}{r_2 + r_3}\right) E_0 \tag{47}$$

The resistance of the artificial line is found experimentally, in actual practice, but can be calculated upon the assumption that the battery is suppressed at the far terminal. The proper values of A and B can be found from (19) and (20) by placing $E_2 = 0$. In any case the apparent resistance is

$$K_0 = K\left(\frac{B + A}{B - A}\right) \tag{48}$$

and when $E_2 = 0$ it is

$$K_0 = K\left(\frac{1 - \alpha_2\, \epsilon^{-2\beta l}}{1 + \alpha_2\, \epsilon^{-2\beta l}}\right) \tag{49}$$

whence

$$r_3 = r_1 + K\left(\frac{1 - \alpha\, \epsilon^{-2\beta l}}{1 + \alpha\, \epsilon^{-2\beta l}}\right) \tag{50}$$

and

$$\alpha = \frac{K - r_0}{K + r_0} \tag{51}$$

When the line is so long that its working limit is approached, (50) is approximately

$$r_3 = r_1 + K \tag{52}$$

When the line is perfectly insulated, or approximately so,

$$r_3 = r_1 + \frac{l\,r}{2} + \sqrt{\left(r_1 + \frac{l\,r}{2}\right)^2 + r_2\,(2\,r_1 + l\,r)} \tag{53}$$

Returning to the consideration of the line currents, it is evident that when the batteries are in conjunction the constants A and B will be found by substituting (47) for E_0 in (33) and (34), or

$$A = \frac{-\left(\frac{1+\alpha}{2}\right)\epsilon^{-\beta l}\,.E_0'}{1-\alpha\,\epsilon^{-\beta l}} \tag{54}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right)E_0'}{1-\alpha\,\epsilon^{-\beta l}} \tag{55}$$

When the batteries are in opposition the constants can be found from (19) and (20) by reversing the sign of E_2, or

$$A = \frac{\left(\frac{1+\alpha}{2}\right)\epsilon^{-\beta l}\,.E_0'}{1+\alpha\,\epsilon^{-\beta l}} \tag{56}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right)E_0'}{1+\alpha\,\epsilon^{-\beta l}} \tag{57}$$

The terminal current at X when the batteries are in conjunction (reversal at Y) is

$$I_1 = \frac{\left(\frac{1+\alpha}{2}\right)(1+\epsilon^{-\beta l})\,E_0'}{K\,(1-\alpha\,\epsilon^{-\beta l})} \tag{58}$$

and in normal opposition the current is

$$I_1' = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-\beta l})\,E_0'}{K\,(1+\alpha\,\epsilon^{-\beta l})} \tag{59}$$

and the ratio is

$$\phi = \frac{I_1'}{I_1} = \frac{\epsilon^{\beta l} + \alpha\,\epsilon^{-\beta l} - (1+\alpha)}{\epsilon^{\beta l} + \alpha\,\epsilon^{-\beta l} + (1+\alpha)} \tag{60}$$

This would be the desired solution if the current in the artificial lines remained constant meanwhile, but on the contrary it changes slightly because of the presence of the resistance r_2. The artificial line current I_A is greatest when the batteries are in opposition. When the batteries are normal the artificial line current is in the same direction as the main line current, but exceeds the latter in magnitude and controls the relay. When the home battery reverses, the main line current at the home end reverses at the same time and the artificial line current also reverses, but the former exceeds the latter in magnitude and the net magnetizing force is in the same direction as before, so that the relay does not respond. However, when the distant battery reverses, the main line current at the home end increases materially, and the artificial line current decreases slightly, so that the former now overpowers the latter in magnetizing effect and reverses the relay.

The change in the artificial line current is important to consider. We may observe at once, from the fact that the half-windings of the polar relay are alike, that the change in the artificial line current may be added algebraically to the change in the main line current. The true ratio of the operating currents in the relay is then

$$\Psi = \frac{I_1' + (I_A - I_A')}{I_1} \tag{61}$$

$$= \phi + \left(\frac{I_A - I_A'}{I_1}\right) \tag{62}$$

But

$$I_A = \frac{E_0 - r_2\, I_1}{r_2 + r_3} \tag{63}$$

and hence

$$\Psi = \phi - \left(\frac{r_2}{r_2 + r_3}\right)(1 - \phi) \tag{64}$$

From (60) it can be shown that

$$1-\phi=\frac{2\,(1+\alpha)}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}+(1+\alpha)} \tag{65}$$

And finally

$$\Psi=\frac{\epsilon^{\beta l}+\alpha\;\epsilon^{-\beta l}\left(\frac{3r_2+r_3}{r_2+r_3}\right)(1+\alpha)}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}+(1+\alpha)} \tag{66}$$

which can be put in the form of (41),

$$l=\frac{2.303}{\beta}\;\log_{10}\left[\frac{n\,(1+\alpha)+\sqrt{n^2\,(1+\alpha)^2-4\,\alpha}}{2}\right] \tag{67}$$

where

$$n=\frac{\left(\frac{3\,r_2+r_3}{r_2+r_3}\right)+\Psi}{1-\Psi} \tag{68}$$

This result is in shape for calculation when the operating constants of the relay are known. It is interesting to note that when $r_2=0$ the artificial line current is constant, and in that case

$$n=\frac{1+\phi}{1-\phi} \tag{69}$$

which makes (67) the solution of (60).

It is essential for good operation that the magnetizing force in the relay, when the batteries are in opposition, should be substantially equal to the magnetizing force when the batteries are in conjunction. This is especially desirable as the limit of operation is approached, because then the magnetizing forces are becoming constantly smaller. When the batteries are in conjunction the net magnetizing current is I_1-I_A, referring to (58) and (63), and in opposition the net magnetizing current is $I_1'-I'_A$, referring to (59) and (63). When the limit of operation is approached the value of $\epsilon^{-2\beta l}$ becomes very small, and in that case the value of r_3 given by (50) is substantially

$$r_3=K+r_1 \tag{70}$$

as given by (52).

Using the approximation of (70) it can be shown that

$$\frac{I_1'-I_A'}{I_1-I_A}=-\frac{1-\alpha\,\epsilon^{-\beta l}}{1+\alpha\,\epsilon^{-\beta l}} \tag{71}$$

which is numerically almost unity. This means that the respective magnetizing currents are opposite in direction and nearly equal.

Out of four possible key combinations only two have been considered and the effects have been investigated at only one terminal. But the symmetry of the circuit and the equality of terminals make it unnecessary to consider the others.

Bridge Polar Duplex. The duplex system is sometimes arranged on the bridge principle and in that case the preceding formulæ apply in a general way, but the terminal conditions are different. Moreover, the relay is not actuated directly by the line current. For theoretical purposes the bridge duplex circuit may be taken as shown by Fig. 5.

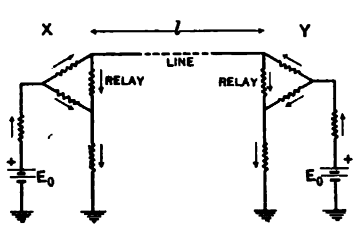

FIG. 5.—Circuit of bridge polar duplex.

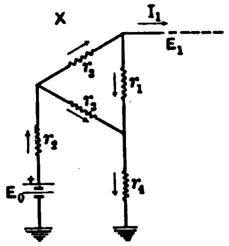

FIG. 6.—Terminal of bridge duplex in theory.

The batteries are normally opposed and the currents then take the directions shown in the illustration. When the distant battery is reversed the current in the home relay is also reversed and the relay then responds; a reversal of the home battery does not change the direction. The home artificial line is balanced as before, by disconnecting the distant battery and grounding; when a perfect balance is thus obtained there will be no current whatever in the home relay, because it occupies a position in the circuit which is analogous to the galvanometer in a balanced Wheatstone bridge.

The terminal conditions will be discussed with the aid of Fig. 6.

The effective terminal resistance is equal to the total resistance of a Wheatstone bridge of which the lower arm r_3 is the galvanometer, measured from line to earth. This is

$$r_0=\frac{r_1\,r_3\,(2\,r_2+r_3)+r_2\,r_4\,(r_1+2\,r_3)+r_3\,r_4\,(r_1+r_3)}{r_3\,(r_1+r_3)+(r_2+r_4)\,(r_1+2\,r_3)} \tag{72}$$

and therefore

$$\alpha=\frac{K-r_0}{K+r_0} \tag{73}$$

The effective e.m.f. is

$$E_0{}'=\left[\frac{r_1\,r_3+r_4\,(r_1+2\,r_3)}{r_3\,(r_1+r_3)+(r_2+r_4)\,(r_1+2\,r_3)}\right]E_0 \tag{74}$$

An investigation of the circuit to determine E_1 in terms of E_0, I_1 and the several resistances gives

$$E_1=E_0{}'-r_0 I_1 \tag{75}$$

This simple expression can now be employed in the general formulæ developed for the differential duplex. It is necessary, however, to have an expression for the current in the relay (which is the leg r_1) in terms of the main line current I_1.

If I_0 is the current in the relay, the expression for it is

$$I_0=\frac{r_3\,E_0-r_3\,(2\,r_2+r_3+r_4)\,I_1}{r_3\,(r_1+r_3)+(r_2+r_4)\,(r_1+2\,r_3)} \tag{76}$$

The apparent outgoing resistance of the line is given by (48) and (49). The value of the artificial line resistance in this case is

$$r_4=K\left(\frac{1-\alpha\,\epsilon^{-2\beta l}}{1+\alpha\,\epsilon^{-2\beta l}}\right) \tag{77}$$

and when $\beta\,l$ is large the expression in parentheses is substantially unity.

No further discussion will be given of this type of duplex operation because the differential method is probably the one most extensively used. In carrying out the full solution it should be remembered, as before, that the limiting condition is the lowest operative current in the polar relay.

Differential Quadruplex. Quadruplex systems fall into two general classes, the differential and the bridge types.. The present treatment will be limited to the former. The derivation of a differential quadruplex from the similar type of polar duplex, by the addition of a neutral relay and a second (larger) source of e.m.f. is very familiar. A full discussion of the operation of such a quadruplex involves the consideration of sixteen key combinations, but the operation of the polar side has already been explained and need not be repeated. Considering the neutral side alone, there are only four key combinations to discuss, with the provision that these combinations should be considered in one case with the batteries in opposition and in the other in conjunction.

For the purpose of theoretical treatment, the essential portion of the quadruplex which represents the neutral side is given in Fig. 7, and will be referred to in discussing the key combinations.

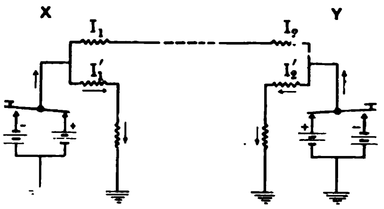

FIG. 7.—Circuit of neutral side of differential quadruplex.

The neutral relay is differentially connected, like the polar relay, but not being polarized it cannot respond to current reversals; it works instead on a current margin, quite like a simple relay in a simplex circuit when there is considerable leakage. When the batteries are in opposition and the ratio of e.m.fs. is 3:1, the relative currents, assuming a perfectly insulated line, are given in Table II.

TABLE II
ELEMENTARY OPERATION OF NEUTRAL SIDE OF DIFFERENTIAL QUADRUPLEX

Key		Relay at *X*			Relay at *Y*		
at *X*	at *Y*	I_1	I_1'	I_1+I_1'	I_2	I_2'	I_2+I_2'
open	open	0	+1	+1	0	+1	+1
"	closed	+2	+1	+3	—2	+3	+1
closed	"	0	+3	+3	0	+3	+3
"	open	—2	+3	+1	+2	+1	+3

The relays respond to a relative current strength of ±3, but remain normal on ±1. When one of the complete batteries is reversed the results are the same, but the current directions are changed. Assuming that the whole battery at Y is reversed, the relative currents are those shown in Table III.

TABLE III
ELEMENTARY OPERATION OF NEUTRAL SIDE OF DIFFERENTIAL QUADRUPLEX

Key		Relay at X			Relay at Y		
at X	at Y	I_1	I_1'	I_2+I_2'	I_2	I_2'	I_2+I_2'
open	open	—2	+1	—1	+2	—1	+1
"	closed	—4	+1	—3	+4	—3	+1
closed	"	—6	+3	—3	+6	—3	+3
"	open	—4	+3	—1	+4	—1	+3

The terminal conditions, except for the impressed e.m.f., are the same as those given in the discussion of the differential duplex.

$$E_1 = E_0' - r_0 I_1 \tag{78}$$

$$E_0' = \left(\frac{r_3}{r_2+r_3}\right) E_0 \tag{79}$$

$$r_0 = r_1 + \frac{r_2 r_3}{r_2+r_3} \tag{80}$$

and the value of r_3 is given by (**50**). In this case the resistance r_1 includes both the polar and the neutral relays. The value of E_0 here assumed is the low value, sufficient only for operating the polar side. The high value of e.m.f. is assumed to be $p\,E_0$ and the ordinary value of p is anywhere between three and four. The terminals are assumed to be identical.

Taking first the case when the batteries are in opposition, the constants A and B are given by (**56**) and (**57**). The line current at X when the keys are normal is the same as (**59**), or

$$I_1 = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-\beta l})\,E_0'}{K\,(1+\alpha\,\epsilon^{-\beta l})} \tag{81}$$

When the battery at Y has p times its normal value, the constants are

$$A = \frac{\frac{1+\alpha}{2}\,(p-\alpha\,\epsilon^{-\beta l})\,\epsilon^{-\beta l}\,E_0'}{1-\alpha^2\,\epsilon^{-2\beta l}} \tag{82}$$

$$B=\frac{\frac{1+\alpha}{2}\,(1-p\,\alpha\,\epsilon^{-\beta l})\,E_0'}{1-\alpha^2\,\epsilon^{-2\beta l}} \tag{83}$$

and the line current at X is

$$I_1'=\frac{\frac{1+\alpha}{2}\,[(1+\alpha\,\epsilon^{-2\beta l})-p\,(1+\alpha)\,\epsilon^{-\beta l}]\,E_0'}{K\,(1-\alpha^2\,\epsilon^{-2\beta l})} \tag{84}$$

The current in the artificial line is

$$I_A=\frac{E_0-r_2\,I_1}{r_2+r_3} \tag{85}$$

The direction of the net magnetizing current in the neutral relay has no effect upon the operation and if ϕ is the limit of releasing to operating current, then

$$\phi=\frac{I_A-I_1}{I_A'-I_1'} \tag{86}$$

Or,

$$\phi=\frac{E_0-(2\,r_2+r_3)\,I_1}{E_0-(2\,r_2+r_3)\,I_1'} \tag{87}$$

If the values of (81) and (84) are substituted in (87) and use is again made of the approximation,

$$r_3=K+r_1 \tag{88}$$

then the final value of ϕ is,

$$\phi=\frac{1-\alpha\,\epsilon^{-\beta l}}{p-\alpha\,\epsilon^{-\beta l}} \tag{89}$$

The next case to consider is that of batteries in conjunction. When the batteries are equal the line current is the same as (38) and when the battery at Y is $p\,E_0$ the constants A and B are

$$A=\frac{-\frac{1+\alpha}{2}\,(p+\alpha\,\epsilon^{-\beta l})\,\epsilon^{-\beta l}\,E_0'}{1-\alpha^2\,\epsilon^{-2\beta l}} \tag{90}$$

$$B=\frac{\frac{1+\alpha}{2}\,(1+p\,\alpha\,\epsilon^{-\beta l})\,E_0'}{1-\alpha^2\,\epsilon^{-2\beta l}} \tag{91}$$

and the line current at X is

$$I_1' = \frac{\frac{1+\alpha}{2}\left[(1+\alpha\,\epsilon^{-2\beta l}) + p\,(1+\alpha)\,\epsilon^{-\beta l}\right] E_1'}{K\,(1-\alpha^2\,\epsilon^{-2\beta l})} \tag{92}$$

The value of ϕ in this case is

$$\phi = \frac{1+\alpha\,\epsilon^{-\beta l}}{p+\alpha\,\epsilon^{-\beta l}} \tag{93}$$

Expressions (89) and (93) are reducible to the same form, or

$$\beta\,l = 2.303\,\log_{10}\left(\pm\frac{\alpha}{n}\right) \tag{94}$$

where

$$n = \frac{1-p\,\phi}{1-\phi} \tag{95}$$

If the terminal resistance r_0 is equal to the line resistance K, the value of α is zero and obviously in that case

$$\phi = \frac{1}{p} \tag{96}$$

This means, in short, that no matter how great the value of $\beta\,l$ may be, the ratio of the net magnetizing currents in the home relay will be the ratio of minimum to maximum e.m.f. at the far terminal. This ratio is not absolutely exact because it depends upon the approximation of (88), but the error is negligible for large values of $\beta\,l$, or at the limit of working.

While the line might be indefinitely long, apparently, in the critical case of $\alpha = 0$, it is clear at the same time that the net magnetizing currents will progressively diminish as the length of the line increases. Therefore the practical operative limit is fixed by the lowest value of net magnetizing current to which the relay will respond in commercial operation. Let m be this limit; then

$$m = I_A' - I_1' \tag{97}$$

$$= \frac{E_0 - r_2\,I_1'}{r_2+r_3} - I_1'$$

$$m = \frac{E_0 - (2\,r_2+r_3)\,I_1'}{r_2+r_3} \tag{98}$$

Substituting the values of I_1' for batteries in opposition and batteries in conjunction, from (**84**) and (**92**) respectively, and again observing the approximation of (**88**), it can be shown that

$$l=\frac{2.303}{\beta}\log_{10}\left[\frac{p\,(1+\alpha)}{2\,m'}+\sqrt{\left[\frac{p\,(1+\alpha)}{2\,m'}\right]^2\mp\frac{\alpha\,(1+\alpha)}{m'}+\alpha^2}\,\right] \quad (\mathbf{99})$$

where

$$m'=\frac{m\,(r_2+r_3)}{E_0} \quad (\mathbf{100})$$

The $\mp$ sign under the radical is negative for batteries in opposition and positive for batteries in conjunction. The operating limits in the two cases are not quite equal, but the difference is slight and becomes zero in the critical case when $\alpha=0$. The maximum value of l, when β is fixed, corresponds to maximum values of α, p and E_0 and a minimum value of m.

III. VALUES OF INSULATION RESISTANCE

The calculation of limiting distances or line lengths, with wires of given resistances, depends critically upon the minimum value of insulation resistance. This value will obviously occur during heavy or prolonged rainfall, or perhaps during very heavy mist or fog. The atmospheric conditions vary greatly with locality and for present purposes it is necessary, if possible, to consider the average locality. It will be assumed that low insulation due to preventable causes, such as foliage and foreign contacts, is substantially absent.

Insulator types have gone through a long process of evolution, but the types now used for telegraph lines have been practically standard for many years. Glass has been the material used almost exclusively, in the double petticoat form. Porcelain has been used to some extent, but not generally. Considering the advantages of porcelain and the favorable experience had with it in some recent instances, it would appear to be the superior material.

It should be borne in mind that the leakage path of most consequence is over the wet surface of the insulator and rarely through its body. The dry resistances of glass and well glazed porcelain are both sufficiently high to be negligible quantities in relation to line leakage; and if neither absorbs an apparent amount of moisture, the internal conductivity is always negligible.

But the surface conditions are most important, and the surface leakage is the principal factor in the line leakage as a whole. Apparently these conditions have not been studied as they should be; in particular, the standard test of telegraph insulators has been for many years to invert them and partly immerse in water, also filling the hollow interior with water, and measuring the insulation resistance between the two bodies of water. This is an excellent test, after a long soaking, of the resistance of the insulating material itself, but it bears little relation to the conditions of service. The test of most importance is the leakage from line-wire to pin, in normal position on a cross-arm, with precipitation at the heaviest natural rate, both vertical and inclined. It is especially important to have the insulator in position on a cross-arm, so as to secure the rebounding or spattering effect of the rain drops on the top of the arm near the insulator, which tends to wet the under side of the petticoats and break down the surface insulation.

Glazed porcelain and glass have surface characteristics of considerable difference. The surface of the glaze on porcelain is somewhat smoother than glass and appears to wet less readily. There is already some experimental evidence that porcelain insulators of the standard glass form give superior insulation, but the whole subject needs further investigation. No doubt the present lack of data is due in considerable part to the faults of the method of testing which has been so long in vogue.

Referring now to the standard type of glass insulators, the insulation resistance of a line in perfect physical condition and in a pure dry atmosphere will be comparatively high, perhaps fifty megohms per mile. Assuming forty insulators per mile, this implies about two thousand megohms per insulator. During heavy rainfall the same line may have an insulation resistance of less than one megohm per mile, or forty megohms per insulator.

The atmospheric purity has a great deal to do, however, with the whole question. Dust is ordinarily present in some degree and forms a coating on the insulator, which impairs its insulation resistance, particularly when wet. Where smoke and soot from soft coal are present, as in many of our cities and nearly always in industrial regions, the insulation is greatly impaired. In the last case it may fall to a few hundredths of a megohm per mile in the worst weather.

The late Franklin Leonard Pope discussed the subject of insulation at some length in his work* on telegraphy. He gave as the average, during rainfall in clean country, 60 to 100 megohms per insulator; and in cities, 4 to 6 megohms per insulator. In the Pittsburg district the resistance was less than one megohm after two years of service. He gave as the average for the middle and northern states 9 megohms per insulator, minimum.

In the author's experience the insulation resistance has been observed to fall to a fraction of a megohm per mile in the worst weather, as a rule, but rarely below 0.25 megohm. Values less than the last figure will be found, of course, but not for lines of any great length in the eastern and central states. The character of the right-of-way has a good deal of influence on the minimum values and in this respect country highways are superior to steam railroads. The best type of insulator is hardly too good for right-of-way of the latter class.

The poles and cross-arms furnish considerable insulation when dry (referring to timber construction), but only a slight amount when thoroughly wet. A wet pole probably adds about 15 per cent to the insulation provided by the insulator alone; this figure resulted from several tests given by Mr. Pope. The old practice of installing a ground wire along the pole tops, uninsulated, practically eliminates whatever insulation the poles provide. A ground wire affords undoubted protection against lightning, and if properly insulated from the poles and periodically grounded through properly insulated connections it would seem to be a good investment.

Two types of pin have long been standard. The steel type, with a wooden thimble, has been extensively employed in telegraph construction, but is less efficient from the standpoint of insulation than the all-wood pin made of locust. The latter type is also the cheaper of the two.

The practice of installing bare lightning rods on about every tenth pole (four per mile) reduces the pole insulation somewhat and it has been claimed that the effect on telegraph transmission is detectable.

The matter of vigilant maintenance to keep broken insulators replaced, foliage trimmed and all foreign contacts clear cannot be over-estimated in importance. Frequent periodical inspections are absolutely essential in securing the best results. Coupled with this there should be frequent periodical tests of insulation resistance. A full discussion of the voltmeter method of meas-

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*" Modern Practice of the Electric Telegraph;" New York, 1892.

uring insulation resistance has been given elsewhere by the author* and will not be repeated.

Another feature worthy of mention is the insulation of bridle cables and office wiring; and in railroad practice, where intermediate offices occur with considerable frequency, it is very essential to look after these parts of the circuit. For convenience in testing there should be test panels, of the telephone jack and plug type, at all terminals and intermediate offices. It is frequently convenient to install test poles, also, where the lines are normally closed, with through line connectors.

Returning to specific insulation values, it is believed to be safe and conservative to base calculations for line conductors on an insulation resistance of 0.25 megohm per mile, or 10 megohms per insulator in a line with forty insulators per mile. Local conditions naturally decide the value to be used in specific work, but for the discussion of average conditions and in all subsequent calculations this value will be employed.

IV. TRANSMISSION REQUIREMENTS

The general theory will now be applied to the actual determination of the conductor properties, for each type of transmission, over given distances. The value of insulation resistance used in all cases, unless otherwise stated, will be 0.25 megohm per mile.

Simplex. Expression (**41**) cannot be employed for numerical calculations until the value of ϕ is determined for relays of the standard type.

The standard relay for many years was one of 150 ohms resistance, wound with about 8,600 turns of No. 30 single silk-covered copper wire. The standard adjustments are tension of retractile spring, length of air gap between poles and armature and play or stroke of armature. The last is the least important, except to emphasize that it should be as small as possible.

Such a relay was set up for laboratory test and first tested for the exact limits of operating and releasing current. The mean of 19 tests showed that the average difference between the operating and releasing currents was 0.003 ampere, with a maximum of 0.004 and a minimum of 0.002. Meanwhile the air gap was varied from minimum to maximum and the spring tension

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*" The Measurement of Distributed Leakage on Transmission Lines;" *Electrical World*, February 6, 1904. " The Voltmeter Method of Measuring Insulation Resistance;" *Telephony*, September 11, 1909.

was similarly varied, employing all combinations of both. Under these conditions the relay action is very slow, of course, being at the limits of actuation. In order to respond at commercial speeds (hand sending) the margin cannot be less than 0.010 ampere, and at this figure the range of adjustment without upsetting the operation is very limited. Table IV shows various possible values of operating and releasing currents and the corresponding values of ϕ and n.

TABLE IV

COMMERCIAL VALUES OF ϕ AND n FOR 150 OHM RELAY

Operating current	Releasing current	Margin	Value of ϕ	Value of n
0.050	0.0400	0.0100	0.80	5.00
"	0.0375	0.0125	0.75	4.00
"	0.0350	0.0150	0.70	3.33
"	0.0325	0.0175	0.65	2.96
"	0.0300	0.0200	0.60	2.50
"	0.0250	0.0250	0.50	2.00

There is a slight advantage in making the operating current as large as possible, because the corresponding values of n will then be a maximum. There is also a further advantage in the added firmness of relay operation.

Similar tests of a standard 35-ohm relay showed an absolute margin of 0.006 to 0.008 ampere, or about double the lower limit of a 150-ohm relay. In order to secure equal advantage with 150-ohm relays in commercial service, the operating current must be somewhat larger than 0.050 ampere. When the operating current is 0.060 ampere, the commercial limit of releasing current is about 0.045 ampere. In all cases the operating limit, with either relay, is obtained with the maximum width of air gap and a relatively high spring tension, which is the characteristic adjustment for operation on leaky lines.

It is also necessary to choose a representative value of terminal resistance, including the complete wiring, equipment and e.m.f. source, from open line to earth. A value of 300 ohms has been selected. This will vary, naturally, with local conditions and the value adopted will be too high in some cases and too low in others. It will be shown later that it is very important to keep this resistance as low as possible.

Adopting these values of n and r_0, as given below, the expression in (41) has been employed to calculate various values of l for given values of r.

$$\left.\begin{aligned} \phi &= 0.75 \\ n &= 4.00 \\ r_0 &= 300 \end{aligned}\right\} \qquad (101)$$

TABLE V

MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	597 miles
3	510
4	450
6	376
8	331
10	299
15	248
20	217
25	195
30	179
40	156
50	140

The results presented in Table V emphasize the need of diminishing wire resistance for increasing distances, assuming continuous service through all weather. They also emphasize the possibility of economizing in conductor cost by the use of cheaper and higher resistance materials than copper for the lines of medium length or less. Thus No. 9 B. & S. copper wire has a limit of nearly 450 miles (724 km.); it is obviously bad economy to employ the same wire for a 200-mile (322 km.) line, where the conductivity of a No. 16 B. & S. copper wire meets the requirements.

It becomes possible, with these results, to make a rigid comparison of the first cost and the annual charges for various conductor materials, under like or known conditions of service.

The properties of the relay are by no means unimportant in their effect on the limit of working distance or line length. The following Table VI illustrates the variation in the line length with variable values of ϕ, for a wire of 10 ohms per mile (1.6 kg.).

TABLE VI
EFFECT OF RELAY CHARACTERISTICS ON THE LENGTH OF A LINE OF 10 OHMS PER MILE

Value of ϕ	Value of n	Limiting length of line
0.80	5.00	335 miles
0.75	4.00	299
0.70	3.33	269
0.65	2.96	249
0.60	2.50	221
0.50	2.00	181

This table shows not only that the relay characteristics have an important bearing, but it illustrates the fact that the inability of a telegraph operator to adjust his relay properly will produce the same results as an inefficient relay.

In fact any influence which tends to reduce the relay margin tends at the same time to increase the cost of transmission by requiring a wire of greater conductivity. For example, the practice of operating two or more lines from a single gravity battery produces this result, because of the comparatively high internal resistance. The latter in turn causes the terminal e.m.f. to change every time any line circuit opens or closes, and thus disturbs the current values in every other line. Under such conditions a value of ϕ as high as 0.75 can rarely be maintained, if at all. If the normal line current of 0.050 ampere is reduced somewhat, the effect is reduced also; but this probably introduces a small loss in the value of ϕ, even with a constant e.m.f. It is quite possible to compute the exact effect, in terms of annual charges, of adding a second line circuit to a gravity battery; but the problem will not be undertaken here. It is fairly clear, however, that the practice ought to be condemned where very long lines are supplied from any type of e.m.f. source having high internal resistance.

The results already presented deal with through circuits, without intermediate offices. Way stations are ordinarily distributed with fair regularity, as a study of railroad mileages between stations, for example, will show. For way circuits the 35-ohm relay is particularly adapted because of its low resistance. When the stations are distributed at fairly uniform intervals there is a very small error in assuming that the resistance of the intermediate relays acts as though it were uniformly distributed in the line wire itself. Relays of 35 ohms, distributed every 10 miles (16 km.) may therefore be assumed to increase the wire resistance 3.5 ohms per mile; and every 5 miles (8 km.), to increase it 7.0 ohms per mile. The results are as follows, showing the comparison with Table V, given in Table VII.

TABLE VII
EFFECT OF 35-OHM INTERMEDIATE RELAYS ON THE MAXIMUM PERMISSIBLE LINE LENGTH

Resistance of wire per mile	Limiting length of line		
	Through circuits	Way stations every	
		10 miles	5 miles
2 ohms	597 miles	391 miles	313 miles
3	510	363	299
4	450	341	286
6	376	305	265
8	331	280	248
10	299	260	234
15	248	225	208
20	217	201	188
25	195	183	174
30	179	170	162
40	156	150	144
50	140		

The effect of intermediate offices is more marked, naturally, on the longer lines of relatively low wire resistance. But 40 offices is probably the extreme limit on way wires; at average intervals of 5 miles (8 km.) the increased conductivity required, as compared with a through wire, is not very marked, while a 10-mile (16-km.) interval requires a much larger increase, relatively.

The result expressed in (**41**) is not in the proper form to find r, the wire resistance, directly in terms of l, the line length. But (**41**) can be put in another form, as given below.

$$w = \frac{0.1886\, W g\, l^2}{\left[\log_{10}\left(\frac{n\,(1+\alpha)+\sqrt{n^2\,(1+\alpha)^2-4\,\alpha}}{2}\right)\right]^2} \qquad \textbf{(102)}$$

where W = the weight of the mile-ohm in pounds per mile.

g = leakage conductance per mile in mhos.

l = the desired length of line.

w = the necessary weight of line-wire in pounds per mile.

This expression is suited for approximate calculations in almost any case, but exact values cannot be obtained unless the value of α is known in advance. The value of α depends in part on the result, and a sensible error in the assumed value will produce some error in the result and necessitate re-calculation.

The expression is of special interest, however, because it shows that for constant values of n, α, g and W, the cost of the wire per mile increases as the square of the length of the line; and the cost of the whole wire increases as the cube of the length. The cost of the entire line construction will not increase quite as rapidly, however, because there are other elements in the unit cost which increase but slowly with the weight per mile and not at all with the length.

It is quite clear from this, without further analysis, that there will be an economic limit to the line distance which can be operated without automatic repeaters. This should hold, at any rate, for circuits where the number of repeater sets is within the limits of commercial operation. In transcontinental circuits, of great length, the number of repeater sets necessary from the standpoint of economics may exceed the number which is permissible from the standpoint of satisfactory speed. Five or six sets is probably the limit from the last point of view.

An inspection of (**41**) to ascertain the maximum value of l, when β is constant, shows that n and α should each be a maximum. The values of n have already been discussed. The maximum value of α is $+1$, when $r_0 = 0$; the minimum value is -1, when $r_0 = \infty$ or the terminal circuit is open. Expression (**41**) can be altered slightly in form, to

$$l = \frac{2.303}{\beta} \log_{10} \left[n \left(\frac{1+\alpha}{2} + \sqrt{\left(\frac{1+\alpha}{2} \right)^2 - \frac{\alpha}{n^2}} \right) \right] \qquad \textbf{(103)}$$

$$= \frac{2.303}{\beta} \left[\log_{10} n + \log_{10} \left(\frac{1+\alpha}{2} + \sqrt{\left(\frac{1+\alpha}{2} \right)^2 - \frac{\alpha}{n^2}} \right) \right] \qquad \textbf{(104)}$$

Or,

$$l = l_0 + l' \qquad \textbf{(105)}$$

where

$$l_0 = \frac{2.303}{\beta} \log_{10} n \tag{106}$$

and

$$l' = \frac{2.303}{\beta} \log_{10} \left(\frac{1+\alpha}{2} + \sqrt{\left(\frac{1+\alpha}{2} \right)^2 - \frac{\alpha}{n^2}} \right) \tag{107}$$

When $r_0 = K$ there is no terminal reflection and $\alpha = 0$. In that case the value of l' is zero and therefore

$$l = l_0 = \frac{2.303}{\beta} \log_{10} n \tag{108}$$

and if $n = 4$,

$$l = \frac{1.387}{\beta} = \frac{1.387}{\sqrt{r\,g}} \tag{109}$$

When α is positive the value of l' is positive and when α is negative the value of l' is also negative. In other words, any value of α less than zero is a detriment to transmission and any value greater than zero is a help. The following Table VIII shows the value of the logarithmic portion of expression **(107)** for various values of α, when $n = 4.0$.

TABLE VIII
VALUES OF LOGARITHMIC ELEMENT IN TERMINAL EFFECT

Value of α	$\left(\frac{1+\alpha}{2}\sqrt{\left(\frac{1+\alpha}{2}\right)^2 - \frac{\alpha}{n^2}}\right)$	$\log_{10}(\ \ )$
1.0	1.968	0.2940
0.8	1.772	0.2485
0.6	1.576	0.1976
0.4	1.382	0.1405
0.2	1.190	0.0756
0.0	1.000	0.0000
—0.2	0.815	—0.0888
—0.4	0.639	—0.1945
—0.6	0.485	—0.3143
—0.8	0.345	—0.4622
—1.0	0.250	—0.6021

By referring to (104) it is apparent that a comparison of $\log_{10} n$ with the last column of Table VIII will show the relative effects of terminal reflection, or the terminal gains and losses. When $n=4.0$, the value of $\log_{10} n$ is 0.6021. The next succeeding table shows the ratio of l' to l_0 when $n=4$, and also the values of l' and l_0 for a line of 10 ohms wire-resistance per mile. In this case,

$$\beta=\sqrt{10\times4\times10^{-6}}=0.006325 \qquad (110)$$

and

$$l_0=219.2 \text{ miles } (352.75 \text{ km.}) \qquad (111)$$

Care should be taken in such calculations as these to use the true logarithms of numbers less than zero, instead of the ordinary cologarithms.

TABLE IX
EFFECTS OF TERMINAL

Value of α	$\frac{l'}{l_0}$	Line of 10 ohms per mile		
		l_0	l'	l_0+l'
1.0	48.8%	219	107	326
0.8	41.3	"	90	310
0.6	32.8	"	72	291
0.4	23.3	"	51	270
0.2	12.6	"	28	247
0.0	00.0	"	0	219
—0.2	— 14.7	"	— 32	187
—0.4	— 32.3	"	— 71	148
—0.6	— 52.2	"	—114	105
—0.8	— 76.8	"	—168	51
—1.0	—100.0	"	—219	0

The benefits of a relatively large value of α are fully apparent from the table. This means that the terminal resistances should be as small as possible in every case. This is a precaution which is much neglected in practice, but ought to receive careful attention. Where generator sources of e.m.f. are employed, the protective lamp resistances should be graded in proportion to the voltage.

It also shows that when the cost of current supply from batteries is compared with the cost of current from generators or storage batteries, for example, the effect of the respective internal or protective resistances should be taken duly into account.

If the total internal resistances of the e.m.f. sources and their protective devices are not alike, the one which has the highest resistance will be the least efficient and can only be compensated for by an increase in the conductivity of the line, with attendant increase in investment and annual charges. When a generator source is employed there should but one line supplied through any lamp (protective resistance)—or one lamp per line.

Duplex. Expressions (67) and (68) cannot be employed for calculations until the operating characteristics of polar relays have been determined and representative values of terminal resistance chosen.

Three typical polar relays were tested to find the lowest commercial reversing current when energizing one-half of the relay, or one of the half-windings. The " Bunnell " type is one of the earliest relays employed in duplex service and is still used. More recently the " Stroh " type has come into use, both for duplex and quadruplex service. Table X shows the results of these tests.

TABLE X
TESTS OF POLAR RELAYS

Type of relay	Total resistance (ohms)	Reversing current	
		Minimum (amperes)	Commercial (amperes)
Bunnell..........	750	0.002	0.004
Stroh............	600	0.002	0.004
"	800	0.002	0.004

The minimum current upon which the relay will reverse, as above given, is the extreme limit and does not operate the relay fast enough or firmly enough for commercial service. The commercial value given in the table is sufficient for good commercial service. In these tests every effort was made to secure a neutral or unbiased adjustment, with the smallest practicable stroke of the armature.

The normal line current in a duplex circuit, with the batteries in conjunction, is about 0.030 ampere. Assuming for the moment that the current in the artificial line is constant, independent of battery reversals, it is obvious that expression (61) for Ψ could be derived instead from

$$\Psi = \frac{I_1 - 2\,I_0}{I_1} \tag{112}$$

where I_1 is the line current with batteries in conjunction and I_0 is the minimum value of reversing current. If the value of I_0 is 0.004 ampere and I_1 is 0.030 ampere,

$$\Psi=\frac{0.030-0.008}{0.030}=0.733 \tag{113}$$

The value of Ψ can be increased, naturally, by increasing I_1; when the latter is 0.040 ampere the value of Ψ would be 0.800. A conservative value of Ψ is probably 0.75 and that value has been used in the calculations which follow.

The total resistance of the polar relay has been taken as 800 ohms and the internal battery resistance (or protective lamp resistance) as 300 ohms, or

$$\left.\begin{aligned} r_1&=400 \\ r_2&=300 \end{aligned}\right\} \tag{114}$$

The substitution of these values in (67) and (68) gives results shown in Table XI.

TABLE XI
MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	783 miles
3	658
4	580
6	485
8	425
10	384
15	318
20	278
25	250
30	229
40	200
50	180

A comparison of these line distances with those for simplex operation, given in Table V, shows considerable increase, which amounts approximately to 30 per cent. This increased efficiency is due mainly to the fact that operation is secured by battery reversals. In simplex operation the battery is merely disconnected, but the efficiency would be much increased if the battery were reversed; this would not be feasible, however, for circuits with intermediate stations.

It will be seen that (**67**) for duplex transmission is identical in form with (**41**) for simplex transmission, although the values of n are unlike. The same conditions in general hold for maximum efficiency, that is, maximum values of n and α. The value of n can be increased somewhat at the expense of α, but it is best in general to keep the terminal resistance as low as possible.

Quadruplex. Three types of neutral relays were thoroughly tested to determine their operating characteristics, employing one-half of the whole winding in each case. A summary of these tests is presented in Table XII, which shows the lowest values of current for commercial operation.

TABLE XII
TESTS OF NEUTRAL RELAYS

Type of relay	Total resistance (ohms)	Minimum commercial operating current (amperes)
Foote-Pierson	300	0.050
Standard	300	0.040
Frier	800	0.030

The absolute margin between operating and releasing currents in the Foote-Pierson relay, averaged from 11 tests, was 0.0074 ampere, with a maximum of 0.010 ampere and a minimum of 0.004 ampere. The value of ϕ could not exceed 0.6 for commercial operation.

The relay of the standard type, which had short magnet cores, developed an absolute margin of about 0.005 ampere. This relay was wound with a total of 5,600 turns of No. 33 enamel wire.

The Frier relay is a self-polarizing type and was the most efficient of the three tested. The average of 10 tests gave an absolute margin of 0.0066 ampere, with a maximum of 0.008 and a minimum of 0.005 ampere.

It should be kept in mind that these margins are the extreme limit of operation and not commercial. The lowest commercial operating currents, using one-half of the whole winding, are given in Table XII.

In selecting the values of terminal resistance the polar relay has been assumed to have 400 ohms and the neutral relay 800 ohms, while the lamp resistance has been taken as 600 ohms. The use of the Field key system does not affect the case, as a consideration of that system* will show.

The low or minimum value of e.m.f. has been taken as 90 volts, with a ratio of 3.5 to 1.0. The whole set of assumed conditions is then,

$$\left.\begin{array}{l} r_1 = 600 \text{ ohms} \\ r_2 = 600 \text{ ohms} \\ E_0 = \;90 \text{ volts} \\ p = 3.5 \\ m = 0.030 \text{ ampere} \end{array}\right\} \qquad (115)$$

The substitution of these values in the formulæ for quadruplex transmission gives the following results.

TABLE XIII

MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	531 miles
3	442
4	386
6	313
8	268
10	236
15	186
20	156
25	135
30	120
40	98.7
50	84.3

In employing expression (99), which has a $\mp$ sign under the radical, the sign was always so taken as to give the lowest value of l. It is notable at once that these operative distances

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*See the Telegraph and Telephone Age, " On the Resistances to Use in the Field Key System," October 1, 1910, p. 666.

are very much less than the distances for duplex transmission and considerably less than the distances for simplex transmission. This result is fully in accord with experience, which shows that the neutral side of a quadruplex always fails first, as bad weather approaches; and the neutral side is less stable as a rule than a simplex circuit under like conditions. It is also well-known that duplex transmission has the greatest margin of all and works under conditions so severe that the simplex and the neutral side of the quadruplex fail completely.

Some actual results of quadruplex operation are very interesting in this connection. The operating conditions of the following circuit were carefully studied. The line was almost exactly 500 miles (804.6 km.) in length, of No. 9 B. & S. copper wire, which included about 8 miles (12.8 km.) of underground cable. The e.m.fs. at one terminal were 290 volts and 85 volts, or a ratio of 1 to 3.4; at the other terminal they were 255 volts and 80 volts, or a ratio of 1 to 3.2, so that an average ratio of 1 to 3.3 was employed in calculations, with an e.m.f. of 85 volts.

The polar relays were wound to a total of 180 ohms, or 90 ohms per side and the neutral relays to 150 ohms per side. The Field key system was employed, but the lamp resistance was only 200 ohms instead of the usual 600.

The resistance of the artificial line for a balance in fair weather was 2,990 ohms; in bad weather the lowest balance at which all four sides of the quadruplex would operate was about 1,800 ohms. The use of expression (**53**) to find the value of r under the given conditions,

$$\left.\begin{aligned} r_1 &= 240^* \text{ ohms} \\ r_2 &= 200 \text{ ohms} \\ r_3 &= 2{,}990+240=3{,}230 \text{ ohms} \\ l &= 500 \text{ miles} \end{aligned}\right\} \qquad (116)$$

gave as an average value

$$r = 5.12 \qquad (117)$$

When the artificial line balance was 1,800 ohms it was found by calculation that the approximate value of K was

$$K = 2{,}000 \qquad (118)$$

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*A value of 250 ohms was used in later calculations.

This value of K in connection with the predetermined value or r gave,

$$g=1.280\times10^{-6} \tag{119}$$

and

$$\left.\begin{aligned} \beta &= 2.560\times10^{-3} \\ \epsilon^{\beta l} &= 3.597 \\ \epsilon^{-\beta l} &= 0.2780 \\ \epsilon^{-2\beta l} &= 0.07731 \end{aligned}\right\} \tag{120}$$

and

$$\alpha=0.6447 \tag{121}$$

Recalling the assumption made in expression (52), it is well to note that in this case

$$\frac{1-\alpha\,\epsilon^{-2\beta l}}{1+\alpha\,\epsilon^{-2\beta l}}=0.9050 \tag{122}$$

instead of unity. This would produce some error in the previous formulæ for duplex and quadruplex transmission, but the true values of K and r_3 were used in the present calculations.

The value of line current calculated from (81) was

$$I_1=0.01950 \tag{123}$$

and the corresponding current in the artificial line was

$$I_A=0.03604 \tag{124}$$

Therefore

$$I_A-I_1=0.01654 \tag{125}$$

The value of line current calculated from (84) was

$$I_1'=-0.01512 \tag{126}$$

and

$$I_A'=0.03912 \tag{127}$$

Therefore

$$I_A' - I_1' = 0.05424 \tag{128}$$

The ratio of the net magnetizing currents in the relay (half-winding) is

$$\phi = \frac{0.01654}{0.05424} = 0.305 \tag{129}$$

The reciprocal of the e.m.f. ratio, $p = 3.3$, is 0.303 and this shows that the ratio of magnetizing currents is almost exactly the ratio of e.m.fs.

The least value of magnetizing current to which the relay would respond commercially is about 0.054 ampere, because any increase in the leakage would necessitate a lower balance than 1,800 ohms, which in turn made the neutral side inoperative. The reason for the failure is found in the fact that greater leakage diminishes the magnetizing currents.

The particularly interesting feature is the fact that the neutral relay used at one of the terminals is the 300-ohm Foote-Pierson relay referred to in table XII whose minimum operating current for commercial service was estimated as 0.050 ampere, or 7.4 per cent less than the value calculated from the actual operating limit. Considering the extent to which judgment enters into such tests and also the ability of an operator to adjust his relay properly, the agreement is fairly satisfactory.

The calculated leakage conductance, given in (**119**), corresponds to an insulation resistance of 0.78 megohm per mile (1.6 km.) The neutral side of this quadruplex failed quite a number of times a year, with every occurrence of fairly heavy weather over the line as a whole.

It is further of interest to know that those in charge of this line had found experimentally that a diminished lamp resistance increased the margin of operation, as we know it should. It was also found that a reduction of the resistance of the polar relay produced the same result without jeopardizing the margin on the polar side, as again we know it should. The operation could be further improved by employing Frier relays and greater value of maximum e.m.f. The standard lamp resistance is 600 ohms and is detrimental to transmission. The resistance of polar relays is generally 800 ohms, which is needlessly high for most lines. The resistances used in the example just given are sufficiently high as a rule.

Summary. The results obtained for the three types of transmission, given in Tables V, XI and XIII, are summarized in Table XIV for comparison, and plotted in Fig. 8.

TABLE XIV
SUMMARY OF LINE LENGTH

Resistance per mile	Maximum permissible length of line		
	Duplex	Simplex	Quadruplex
2 ohms	783 miles	597 miles	531 miles
3	658	510	442
4	580	450	386
6	485	376	313
8	425	331	268
10	384	299	236
15	318	248	186
20	278	217	156
25	250	195	135
30	229	179	120
40	200	156	98.7
50	180	140	84.3

The curves in Fig. 8 permit the determination of the line length for a wire of any stated resistance per mile. They also illustrate clearly the differences in transmission range among the three systems. It is next possible, knowing the weight of the mile-ohm at the desired temperature and the conductor weight per mile, to find the resistance per mile and interpolate the line length from Fig. 8.

The mile-ohms of the line conductors used almost exclusively in telegraph service are given in **(130)** below, for a temperature of 68 deg. fahr.

$$\left.\begin{array}{ll}\text{Hard drawn copper (98 per cent)} & = 895 \text{ lb.} \\ \text{Extra best best iron} & = 4{,}700 \text{ "} \\ \text{Best best iron} & = 5{,}500 \text{ "} \\ \text{Steel} & = 6{,}500 \text{ "}\end{array}\right\} \qquad \textbf{(130)}$$

The values given by different manufacturers for iron vary slightly and so do the conductor weights. The values above are taken from Roebling's tables.

A new type of conductor which deserves special attention for telegraph service is copper-clad steel. A full discussion of its elementary properties is referred to below.* It consists of a steel core with an enveloping copper shell, the metals being welded at the junction. The conductivity of such a wire can be varied within certain limits by altering the proportions of copper and steel. The method of rating is usually in terms of its conductivity ratio to solid copper of equal size. A ratio of 40 per cent has been standardized by one manufacturer and is in considerable use, for various purposes. The rated value of the mile-ohm at 68 deg. fahr. is

$$W = 2{,}075 \text{ lb. } (941 \text{ kg.}) \qquad \textbf{(131)}$$

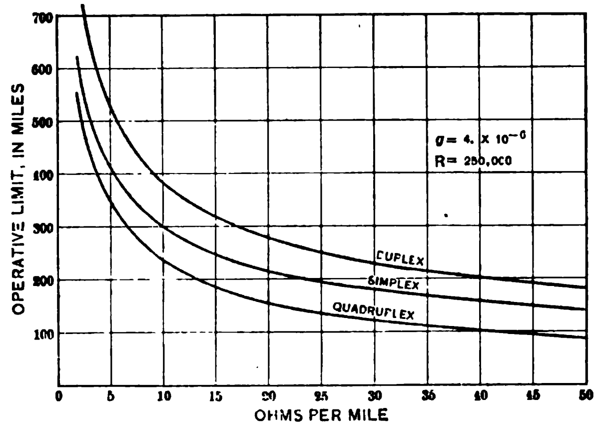

Fig. 8

The tensile strength of wires of this material, in telegraph sizes, is from 90,000 to 100,000 lb. per square inch (6.45 sq. cm.) compared with 60,000 to 65,000 lb. (27,215 kg. to 29,483 kg.) for hard-drawn copper; the elastic limit is approximately 50 per cent more for copper-clad than for copper. The modulus of elasticity for copper-clad, in inch-lb., is from 21,000,000 to 22,000,000, compared with 16,000,000 to 17,000,000 for copper.

Employing these several values of the mile-ohm to determine the resistance per mile for various gauge sizes and then interpolating the line lengths from Fig. 8, gives results as follows, in Table XV, for simplex transmission.

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*"Electrical Properties of Compound Wires," *Electrical World*, December 22, 1910; December 29, 1910; and January 12, 1911.

TABLE XV
MAXIMUM PERMISSIBLE LINE DISTANCES FOR SIMPLEX TRANSMISSION

Gauge number	Maximum line distance				
	Hard-drawn copper (B. & S.)	Copper-clad steel (B. & S.)	E. B. B. iron (B. W. G.)	B. B. iron (B. W. G.)	Steel (B. W. G.)
6	585	397	327	304	282
7	535	358	293	273	252
8	485	322	270	252	233
9	437	290	245	228	211
10	395	261	223	207	191
11	357	235	202	186	173
12	321	211	184	171	157
13	289	188	161	149	
14	260	169	141		

Attention is called to the fact that the gauges in Table XV are not all alike; the Brown and Sharpe gauge is commonly used with copper and copper-clad wires, while the Birmingham gauge is used with iron and steel.

In order to show the general relation between the conductor weight per mile and the line length, the distances given in Table XV and the corresponding conductor weights have been plotted in Fig. 9.

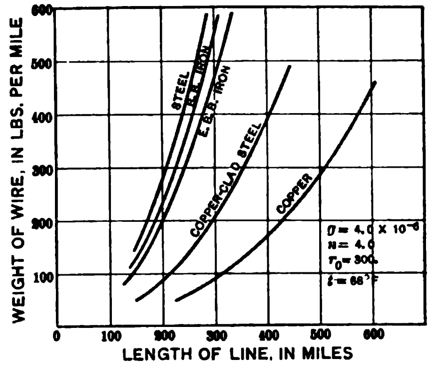

Fig. 9

These curves emphasize again how rapidly the weight per mile increases with the length of the line. They also illustrate the need of making cost studies of transmission to decide the most economical proportions and designs; some of these features have already been pointed out and others will be discussed later in general terms.

Nearly all of the large telephone and telegraph companies have standardized certain gauges of wire, which is obviously desirable in a large wire plant to secure flexibility. The standard conductors in long-distance telephone service have been for many years No. 8 B. W. G. and No. 12 N. B. S. G. hard-drawn copper. The standards for telegraph service have long been No. 9 B. & S. copper and No. 8 B. W. G. iron. Other sizes have been used to some extent, but not generally.

The operative limits of various conductors in use are given in Table XVI.

TABLE XVI
OPERATIVE LIMITS OF VARIOUS CONDUCTORS USED IN TELEGRAPH SERVICE

Gauge	Material	Weight per mile (lb.)	Operative limit (miles)
No. 8 B. W. G......	H. D. copper	435	593
" 9 B. & S.......	" "	209	437
" 12 N. B. S. G....	" "	173	402
" 10 B. & S.......	" "	166	395
" 6 B. W. G......	B. B. iron	573	304
" 8 B. W. G......	" "	378	252
" 10 B. W. G......	" "	250	207

The curve for copper in Fig. 9 shows that it is the lightest material of all for any specified service; and at normal prices it is also the cheapest on a basis of conductivity. But conductivity is not an exclusive consideration; the mechanical properties are fully as important. A long experience with hard-drawn copper in the sleet zones has demonstrated that the strength of No. 9 B. & S. is not capable of withstanding the storms of extreme severity, although it stands up fairly well in moderate storms. No. 12 N. B. S. G. has somewhat less strength than No. 9 B. & S. and will not sustain severe loads of sleet and wind.

If a copper wire of 200 lb. (90.7 kg.) weight per mile (1.6 km.) is regarded as the smallest practicable size, it is evident from Fig. 9, that this size must be used for all lines less than 430 miles (692 km.) in length, until the 200-lb. (90.7 kg.) abscissa intersects the curve for copper-clad steel at about 300 miles (482.8 km.) or the curve for B. B. iron at about 185 miles (297.7 km.).

A detailed cost study is necessary to fix the relative economy of various kinds of conductors, but in general it can be said that copper-clad steel finds its economical field of use in the lines less than 300 miles (482.8 km.) in length, except where automatic repeaters can be employed. In making such a study it ought to be kept in mind that iron and steel wires ultimately corrode and that with the progress of age (and corrosion) they suffer a progressive loss of conductivity and tensile strength. The tensile strength requirements depend in great part on the most severe combinations of sleet and wind which are likely to occur; in the foot-note reference* there will be found an investigation of this subject from conditions prevailing in the vicinity of Chicago, Ill.

Finally, it is pertinent to compare the results obtained from the leakage theory of transmission (over open-wire lines) with the empirical results stated by Mr. Herbert and given in (**2**), (**3**) and (**4**) at the opening of the paper. The results are directly compared, so far as possible, in Table XVII.

TABLE XVII
COMPARISON OF THE *K R* AND THE LEAKAGE THEORIES OF TRANSMISSION

Conductor material and weight per mile	Operative limit	
	K R theory	Leakage theory
150-lb. copper	590	377
100- " "	487	314
450- " iron	363	272
400- " "	291	258

The empirical *K R* rule applies to English practice which employs the open-circuit method, while the leakage theory applies to American practice, or the closed-circuit method. The results are not directly comparable, of course, but tend toward the conclusion that the *K R* theory gives greater operative limits than the leakage theory; or otherwise stated—in the present state of development the operative limit is fixed by considera-

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*" A Study of Sleet Loads and Wind Velocities," *Electrical World*, October 27, 1910.

tion of the Ohm's law strength of signals, rather than the speed of transmission.

The *K R* theory certainly fails to develop the important relations between the properties of the line and the properties of the terminals which are so clearly brought out in the leakage theory. But fundamentally the *K R* law is absolutely inapplicable to open-wire lines for the simple reason that they possess inductance and leakage in addition to the cable properties of resistance and capacity.

V. Relay Design

There has been considerable activity from time to time in relay design and improvement, but it does not seem to be keenly realized that one of the very important things is to keep the terminal resistance at an absolute minimum. The standard 150-ohm and 35-ohm relays have not undergone any material change in design or any improvement in many years. The 35-ohm relay is not the equal in power of the 150 ohm, because it has approximately only half as many turns, and in consequence it requires double the operating current for equal results.

The only possible way in which the resistance can be reduced by improvements in the winding is to increase the winding volume, thus making it possible to employ a larger size of wire without reducing the number of turns. In general this increases the bulkiness of the relay and such a result seems to have been looked upon unfavorably. In the matter of insulation, however, there is room for some improvement by the use of enamel instead of silk, whenever the wire used is smaller than No. 23 B. & S. gauge. This is evident from a consideration of the coefficients of space utilization, or the ratios of copper volume to winding volume. Obviously the thinner the insulation the more turns of a given size of wire can be wound in a stated volume, or for a fixed number of turns, the less will be the resistance. Table XVIII shows the results of a study of space utilization, for enamel, silk and cotton insulation.

The advantages of silk over cotton, and enamel over both, are very clearly shown. It is obviously desirable to employ enamel insulation. An objection has been urged against it in the matter of repairing damaged relays, it being claimed that the wire can be used but once because of the brittleness of the enamel when wound on a very small radius. Considering the small annual maintenance charge per relay and the corresponding saving in line conductor cost which results from a low terminal resistance, it is practically a foregone conclusion that enamel insulation is economical, except possibly for very short or so-called pony lines.

The use of enamel in relays of the neutral type, for quadruplex service, is highly important; because in this case the neutral side is the least stable and every added increment of margin is valuable. Referring to the 800-ohm polar relay of the Stroh type and the 800-ohm neutral relay of the Frier type, previously referred to and tested, and made by the same manufacturer, the polar relay had a total of 14,200 turns of No. 35 B. & S. black enamel wire, while the neutral relay had a total of 14,100 turns of No. 35 B. & S. single-silk covered wire. If there is any choice between these relays as to which one should have enamel insulation—which it seems there is not—the neutral relay should be selected most obviously.

TABLE XVIII
COEFFICIENTS OF SPACE UTILIZATION IN MAGNET WINDINGS

B. & S. gauge	Coefficient of space utilization		
	Single cotton	Single silk	Enamel
24	0.50	0.67	0.68
26	0.46	0.61	0.68
28	0.41	0.57	0.67
30	0.36	0.55	0.64
32	0.27	0.50	0.67
34	0.23	0.40	0.65
36	0.19	0.39	0.62
38	0.14	0.34	0.67
40	0.10	0.29	0.65

The opportunities for improvement in windings generally are well worth taking advantage of, but perhaps the greatest improvement that can be made has to do with the magnetic circuit. The desideratum in a relay of any type is sufficient force of magnetic attraction, between the poles and the armature, to overcome the retractile force and the inertia of the moving system, and to close the local contacts quickly and firmly. The law of magnetic traction, or the force exerted between a pole and its armature, is

$$P = \frac{B^2 A}{8 \pi} \tag{132}$$

expressed in c.g.s. electromagnetic units, where B is the flux density and A is the pole area. It is very well known that when the pole and the armature are in contact, or that is, when the magnetic circuit is closed, the maximum value of P occurs with a minimum value of A. The simple explanation is the fact that halving A, for example, doubles B and quadruples the square of B, and so doubles the value of P. The limit naturally arrives at saturation.

But the introduction of a small air-gap between the pole and its armature, as in the ordinary telegraph relay, establishes a new state of affairs. Assuming a constant number of ampere-turns, it is essential to find the value of A which makes P a maximum. The reluctance of the whole magnetic circuit is comprised in very large part of the reluctance of the air-gap. If ϕ is now the total magnetic flux,

$$\Phi = B\,A \tag{133}$$

and therefore

$$P = \frac{\Phi^2}{8\,\pi\,A} \tag{134}$$

The number of ampere-turns, $n\,I$, required to establish the total flux ϕ in a gap of length l and area A, is

$$n\,I = \frac{10\,l\,\Phi}{4\,\pi\,A} \tag{135}$$

or

$$\phi = \left(\frac{4\,\pi\,n\,I}{10\,l}\right)A \tag{136}$$

and

$$P = \left(\frac{16\,\pi^2\,n^2\,I^2}{800\,\pi\,l^2}\right)A \tag{137}$$

of which the only variable part is A. Therefore the larger the area of the air-gap the larger will be the pull between the pole and the armature. The value of P will not increase quite as fast as A, however, because a small part of the ampere-turns are required to overcome the reluctance of the iron portion of the magnetic circuit, and this part will increase as A increases. But a very substantial increase will result in the pull P, from increasing the area of the gaps in a standard telegraph relay.

This result is directly at variance with the early theories and it is particularly interesting to note Professor S. P. Thompson's reference, in his " Lectures on the Electromagnet," to the experiments of Dr. Julius Dub with polar extensions on bar magnets, made about 1850. Dub found that a polar enlargement *decreased* the pull across a gap, which was later explained, and correctly, upon the theory that the pole piece increased the leakage and diminished the flux which issued straight out from the pole. This was the result obtained with a long bar magnet, which is the direct antithesis of a horseshoe magnet with an armature separated from its poles by a small gap. The correctness of the present conclusions has been proved experimentally with polar enlargements on a telegraph relay of the standard 150-ohm type.

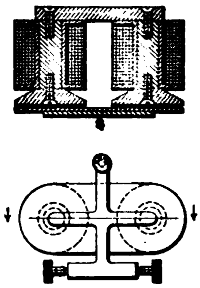

FIG. 10.—Enlarged pole piece and armature, on ordinary type of telegraph relay.

The practical benefit which results from this departure in the construction of the magnetic circuit is the ability to reduce the ampere-turns and the resistance, without sacrificing the intensity of armature pull or attraction now obtained. There are many ways of securing this result. Fig. 10 shows one method which will quickly occur to everyone. A superior method or design is shown in Fig. 11, which is an iron-clad type with a large pole piece on the central core. In the last case a total armature pull of no less than the pull in a standard 150-ohm relay can be obtained with not more than 20 ohms of resistance in the winding.

The tendency in these designs is toward heavier armatures and greater inertia, making it necessary to increase the forces actuating them in order not to sacrifice speed. This can be minimized by using armatures as thin as practicable, mounted on aluminum frames. If the 35-ohm standard relay is taken as a basis, instead of the 150-ohm, the resistance can be reduced somewhat below 20 ohms. In the case of way circuits the improvements will be especially marked.

There has long been a supposition that relays with short magnetic circuits are inherently quicker than relays with long circuits. There are so many variables in relay design, however, that comparisons should be made with extreme care. Fundamentally the quality of iron in the magnetic circuit should be of the best—of high permeability and as nearly devoid of hysteresis as possible. For the most rapid operation the magnetic circuit should be laminated and the laminations should be insulated, in order to secure full magnetic penetration in the shortest time. Solid thick cores are the least desirable in form, because the screening or dissipative effect of eddy currents diminishes the rate of magnetic penetration.

VI. GENERAL IMPROVEMENTS IN TERMINAL CONDITIONS

Aside from the matter of relay improvements it is generally possible to improve telegraph operation by careful attention to the terminal conditions. In particular it should be kept in mind that faults here decrease the operative margin or limit of working distance and can only be compensated for by increased line conductivity. The lamp resistances, where generators are employed, should be made as low as possible; iron filaments should always be employed in the place of carbon, which has a negative temperature coefficient. The resistance of earth connections should also be made as low as possible, and to that end should be measured periodically.

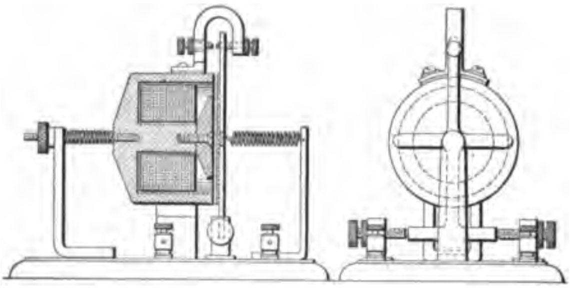

FIG. 11.—Iron-clad relay with enlarged pole areas

A most economical size of office wire can always be calculated for any specific line circuit; and in order to secure flexibility as well as economy, the size used ought to be adequate for all except possibly the very longest lines, which will have special office conductors of the proper size. The matter of office wiring is doubly important on way circuits.

The terminal resistances can be made less as a whole with generators, than with batteries, for e.m.f. sources. Careful cost studies to determine where and when it will be economy to replace battery installations with generators will generally pay for themselves. The rapid development of electric power service all over the country now makes it rarely necessary to rely on batteries or isolated plants, although the latter may pay for themselves in some instances.

Specifically, it seems possible in most cases to do away, in whole or in part, with lamp resistances. These resistances are used mainly to prevent dangerous currents in the case of short-circuits or grounds near the generator—or the terminal office. Of course the resistance is necessary in some cases to prevent sparking at line contacts and cannot be sacrificed in that case without some efficient substitute. But where such is not the case it seems that a circuit breaker of special design would provide the necessary protection with much saving in terminal resistance. In order not to open the line entirely it is proposed that the circuit breaker should normally short-circuit the protective resistance and cut it into circuit upon operation—or whenever the current exceeds the safe limit at which the breaker is set to act. These circuit breakers should be within sight of the wire chief and should give an alarm upon their operation—and if there are many of them, a visual signal also.

VII. Improvements in Line Insulation

The minimum value of insulation resistance experienced in practice is a critical factor in fixing the required line conductance, as already pointed out. In order to show this more effectively the following Table XIX has been computed for a line of 10 ohms resistance per mile, assuming simplex transmission under the conditions previously described.

TABLE XIX
EFFECT OF VARYING LEAKAGE ON A LINE OF 10 OHMS PER MILE, FOR SIMPLEX TRANSMISSION

Insulation resistance megohms per mile	Leakage conductance mhos per miles	Operative limit in miles
1.000	1.0×10^{-6}	624
0.500	2.0×10^{-6}	433
0.250	4.0×10^{-6}	299
0.125	8.0×10^{-6}	204

The table shows that the operative limit in miles increases slightly faster than the one-half power of the ratio of increase in insulation resistance; that is, quadrupling the insulation resistance increases the operative limit slightly more than double. The great saving in line cost which will result from better insulation is perfectly apparent and it is also apparent that the cost of better insulators may double or triple without materially reducing the saving if the gain in insulation is commensurate.

If the insulation could be increased indefinitely an operative limit would be fixed in any case by the inability to signal with requisite speed, but there is a large margin for improvement. For example, several cases have come under the author's observation where circuits of No. 8 B. W. G. iron, 500 to 600 miles in length, have been employed for through simplex or duplex service, without repeaters in good weather; upon the approach of heavy weather automatic repeaters were cut in near the middle of the line. If such a circuit measured 10,000 ohms in clear weather, it would require only 250 volts at each terminal to secure a line current of 0.050 ampere, which is well under the voltage limit for telegraph circuits in general, except composited telephone circuits.

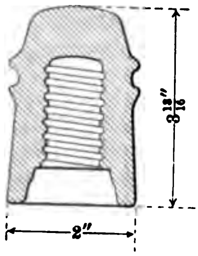

FIG. 12.—Standard glass insulator for telephone lines

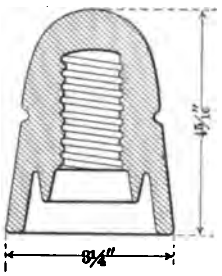

FIG. 13.—Standard glass insulator for telegraph lines

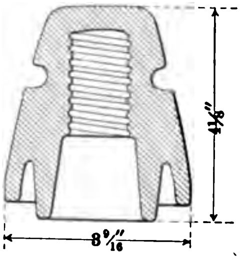

FIG. 14. — Porcelain insulator for loaded telephone lines

There are two possible methods of improving the insulation. The first is the reduction of the number of poles per mile and consequently the number of insulators. In general this method is inapplicable except on lines carrying very few wires, because it requires greater sag in the spans, higher poles and increased horizontal separation between adjacent wires. The second method, which holds the greater potential possibilities, is the adoption of better insulators.

Two types of insulators now in very extensive use are shown in Figs. 12 and 13. The first is the standard glass insulator for telephone service and the second is the standard glass insulator for telegraph service. A recent type of porcelain insulator for loaded telephone lines is shown in Fig. 14. The latter represents an effort to secure better insulation and is of special interest for that reason. It was learned some years ago, after the first attempts to load long telephone circuits of No. 8 B. W. G. copper, that the normal gain in transmission could not be maintained in heavy weather, because of the low insulation—a result which was quite in accord with the full theory of the subject. In fact, when the insulation was very low, the loading caused an actual loss in transmission as compared with an unloaded circuit. The insulator in Fig. 14 is reported to give satisfactory results in the brief experience with it up to this time.

These three insulators are all of the same general type, mounted on a pin, directly above and rather close to the cross-arm. In common they possess the disadvantage that the impact of heavy rainfall on the cross-arm tends to spatter the under sides of the petticoats and thus impair the insulation resistance. The insulator shown in Fig. 15 is designed to relieve this condition somewhat, but it is very difficult to do so without increasing the length of the pin and thus increasing the stresses in the cross-arm, at times.

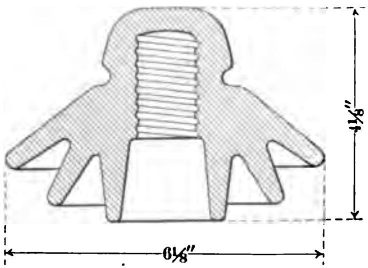

Fig. 15.—Improved type of porcelain insulator for telegraph lines

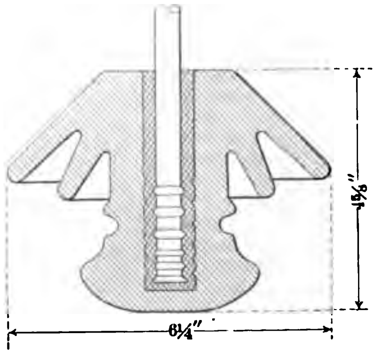

Fig. 16.—Under hung type of porcelain insulator for telegraph lines

The possibility also suggests itself of adopting an under-hung insulator, of the pin type. Such a type is shown in Fig. 16; it seems to offer greater probability of a comparatively dry interior than any of the previous types. The large petticoat serves both to shed the water which comes from the cross-arm and shelter the interior. No water could reach the interior by impact or by spattering; if the line were on a hillside, a small amount of water might trickle down the line wire and wet the tie, but it would then drain to the under flange and drip to ground.

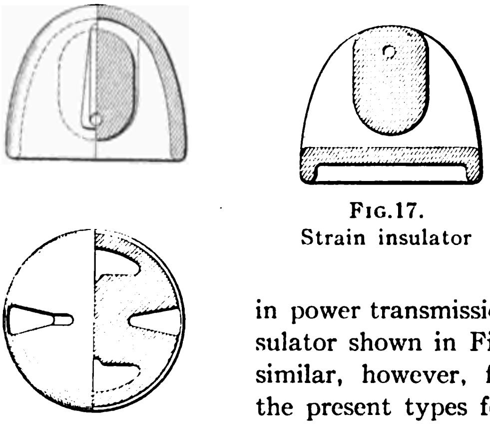

FIG. 17. Strain insulator

It is but a step further in evolution to the more radical proposal for an insulator of the suspended or strain type, now familiar in power transmission. The insulator shown in Fig. 17 is dissimilar, however, from any of the present types for the latter purpose. It is specially designed to obtain as dry an interior as possible and consequently has an extended shell or petticoat. The suspension is of the link type, submitting the porcelain to compression stresses almost entirely. The hole for the upper suspension is made straight at the bottom so as not to hold water, which might otherwise collect and freeze, thus splitting the insulator by its expansion. As much room as possible is provided in the interior for the insertion of the lower suspension, between the shell and the bridge. Fig. 18 shows the general method of suspension and a particular method of attachment to the line

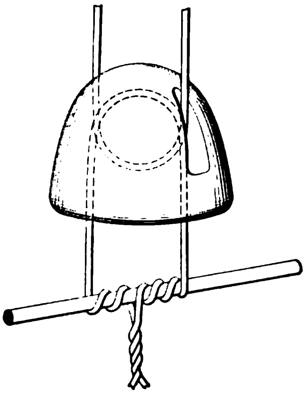

FIG. 18.—Strain insulator, showing suspension

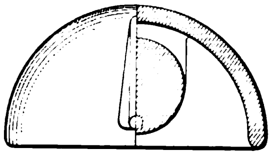

FIG. 19.—Strain insulator

wire. Fig. 19 shows the same general design with greater flare of the shell. This general type of insulator will only serve for tangent portions of a pole line, where all the stresses of the line wire lie in a vertical plane; at corners and curves the rigid suspension is necessary. It will permit slightly greater swinging of spans than ordinarily occurs with rigid suspensions and on that account it will be necessary to increase the horizontal separations slightly. In long tangents it will be necessary to introduce rigid suspensions for anchorage purposes, at periodic intervals.

The natural flexibility of this type of construction gives it some advantages under severe loads of sleet and wind. The breaking of a single conductor does not ordinarily relieve adjacent spans, but in this case it would do so for some distance and thus tend to prevent the complete stripping of wire which occurs frequently in severe sleet storms.

The strain type of insulator is better adapted to pole lines carrying a few wires than to lines heavily loaded, on account of the greater horizontal separation needed. At the same time, however, it can be used to increase the wire capacity of present lines, by stringing new circuits between arms. For special purposes, such as patrol circuits on or parallel to transmission lines, it also has advantages.

In general the proposal to change the types of line construction may seem radical to the telegraph field, which has been accustomed for so many years to fixed standards. But one of the greatest potential dangers in standardization lies in the fact that it may be overdone and given standards persisted in too long, at the sacrifice of progress and efficiency.

DISCUSSION ON "TELEGRAPH TRANSMISSION." CHICAGO, JUNE 28, 1911.

Bancroft Gherardi: Mr. Fowle's paper, which I have been asked to discuss, is one of particular interest, as it undertakes to present and to treat in a scientific manner a number of telegraph problems in the same way which has been so successful in dealing with problems concerning telephone work, power transmissions and electric light work. But few papers have been presented recently in this country which have dealt with telegraph problems as though they were controlled by the same physical laws as are the other branches of the electrical art. I have had so little time since I received the copy of this paper that I have been unable to study the mathematical proportion of the paper, but I have been over the rest of it, and the results which Mr. Fowle states have been attained in practice are, in general, in accordance with our experience.

The paper covers the subject from so many different aspects that it will be impossible for me, in the time to which my discussion is limited, to speak of many interesting questions which it raises. On two points, however, I should like to say a few words.

Mr. Fowle gives an interesting discussion of the problem of insulating telegraph lines. This is a very important question and one to which much study has recently been given in the telephone field, with the result that we are trying out a number of special designs of insulators, both of porcelain and glass. The paper suggests that a suspended insulator be adopted on certain telegraph lines. Much time and study will have to be given to this question before it is demonstrated that it will be necessary to make such a radical departure from existing insulator methods in order to obtain the desired results. A great many mechanical difficulties would have to be overcome in connection with the use of such insulators on telegraph lines, and it does not seem to me that it is as yet by any means demonstrated that we cannot, by the use of insulators of suitable material and suitable design, and supported on pins in the usual manner, obtain the desired results more cheaply and more satisfactorily than by the use of a suspended insulator. The suggestion in question is an interesting one, however, and I am very glad that it has been made, but it is my feeling at the present time that other and less radical methods are likely to accomplish the desired results.

The author's suggestion that much use might be made of copper steel wire for telegraph circuits raises at once a serious question in my mind. This wire has, I believe, in general, an ohmic resistance of about 2½ times that of hard drawn copper wire of the same diameter. It would, therefore, seem to me that the same reasons which have led the telegraph companies to so generally employ in their more important circuits hard drawn copper wire instead of iron would deter them from employing a material which would represent a step backwards in this most important characteristic of a line.

Frank F. Fowle: The points brought out by Mr. Gherardi in relation to suspended insulators for telegraph lines I believe are well taken. The choice of a satisfactory insulator is necessarily a compromise between cost and efficiency, and on that score everyone seems to agree that the ordinary glass insulators now in service can be much improved upon. The question is how far we can go in the direction of better efficiency before the cost becomes too great—or in other words, where is the point of maximum commercial efficiency.

Before we can answer this question it is necessary to know what we can accomplish in improving the physical efficiency, without regard to cost. After settling that part of the problem, a cost study will fix the highest point of efficiency which is commercially feasible. My proposal for suspension insulators does not go farther than the first stage of the problem, and is along the line of obtaining the highest degree of insulation which is physically possible. An insulator of the suspension type is admittedly objectionable from a mechanical standpoint where the line wires are crowded together on the pole line, with the smallest feasible separation. On the opposite hand it seems to possess numerous advantages where the wires are few in number, comparatively, and the climatic conditions to be met are severe. It is probably too soon to state any conclusions as to what forms and types of insulators will finally survive as commercially the fittest for various classes of telephone, telegraph and signal service.

Mr. Gherardi's remarks in relation to the use of copper steel wire—or as it is more familiarly known, copper clad steel—indicate that he is thinking principally of conductivity, without full regard for other requirements. Tensile strength is a factor quite as important as conductivity.

The commercial field for any conductor of a new type, such as copper clad steel, is necessarily a question of economics. The latter phase of the subject has not been treated in the present paper, but it will be found in somewhat extended form in my paper on "Line Conductor Requirements for Telegraph Transmission," read before the Association of Railway Telegraph Superintendents, at the annual convention of this year. The latter paper contains a full substantiation of the statement made by me in the present paper, that copper clad steel finds its economical field in the lines less than 300 miles in length, approximately, where no repeaters are employed. If automatic repeaters are made use of, the economical range of copper clad steel wire is limited only by the feasible number of repeater sets from an operating standpoint. One set will extend the range to about 600 miles and two sets to 900 miles.

The substitution of copper wires for iron by the telegraph companies is probably traceable to several causes. The difficulty of maintaining iron wire in good condition has increased of late years, owing both to the use of inferior metals in manufacture and to the more general presence of corrosive agents in the atmospheres of cities, industrial regions and along steam railroads. The difficulties are increased by the fact that the life of the joints is not equal to the life of the body of the wire. Joints deteriorate rapidly and increase in ohmic resistance. The substitution of copper greatly diminishes the rate of depreciation, because the oxide coating on the surface of copper is protective and arrests further corrosion while it remains intact.

Owing to the fact that the tensile strength of hard-drawn copper does not exceed approximately 65,000 lb. per sq. in., it is not feasible to employ small wires, except in mild climates. The telegraph companies have settled on a standard of No. 9 B. & S., weighing 209 lb. per mile, which has a breaking strength of about 620 lb.

The use of copper clad steel wire in place of this conductor is not economical except where the conductance of No. 9 copper is in excess of the transmission requirements. For example, the use of No. 9 copper for a telegraph line 150 miles long is an economic waste of copper, because a much smaller conductor would provide the necessary conductance. At the same time the correct size of copper from a conductance standpoint would not be strong enough to sustain loads of wind and sleet, and would not give reliable service—if in fact it would stay up at all.

Such a case forms an ideal illustration of the value of copper clad steel wire, whose tensile strength is approximately 90,000 to 100,000 lb. per square inch. This type of wire could be substituted for solid copper, in this instance, with considerable saving in cost, because its superior tensile strength permits the use of smaller sizes than are permissible with copper.

Of course the substitution of copper clad steel for copper, where the size of copper needed electrically is also sufficiently strong mechanically, is out of the question. Had my statement that copper clad steel is an economical and suitable telegraph conductor been unaccompanied by the important qualification that 300 miles is the limit on its use in circuits without repeaters, Mr. Gherardi's general objection on the score of low conductivity would be well sustained. But in the light of all the analysis of the problem it seems to be clearly established that the superior strength of copper clad steel wire, taken in conjunction with present market prices, proves it in for distances in simplex service up to about 300 miles.

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